Agriculture and Development

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Ph.D. thesis by

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Contents

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Asger Moll Wingender

Summary

Agriculture (including fishing) was from the onset of the Neolithic Revolution to the eve of the Industrial Revolution the dominant sector around the globe. By the early 19th century, manufacturing had overtaken agriculture in the United Kingdom, from where the Industrial Revolution gradually spread to other parts of Europe and the English speaking world. The transition out of agriculture was accompanied by economic growth unprecedented in human history. All countries that have failed to accomplish the transition have also failed to grow, and remain poor in the present day. Understanding the role of agriculture in the economy is consequently crucial to the understanding of economic development. It is also important for an understanding of political development. The historical prominence of agriculture in the economy gave special interests in the agricultural sector a substantial and lasting impact on political institutions.

This Ph.D. thesis contributes to the understanding of the interplay between agriculture and both economic and political development. The thesis consists of three separate research articles.

The first article, *Structural transformation in the 20th century: A new database on agricultural employment around the world*, is motivated by the many empirical questions about economic growth and development that are left open by the lack of long time series of reliable GDP estimates. In the article, I argue that the share of the labor force employed in agriculture can fill this gap. Agricultural employment shares are highly correlated with GDP per capita, less prone to measurement errors, and data are available for longer periods than existing GDP estimates.

The article describes a new database on agricultural employment in 169 countries for the period 1900-2010. In years where no employment data are available, urbanization rates are used to estimate agricultural employment shares. Some of the many potential uses of the data are discussed.

In the second article, *Skill complementarity and the dual economy*, I turn to the theoretical relationship between agricultural employment, national income, and human capital. A significant contributor to the low income levels observed in developing countries is their large

agricultural sectors that are relatively unproductive compared to other parts of the economy. In developed countries, by contrast, sectoral productivity differences are relatively small. In the article, I estimate that the elasticity of substitution between skilled and unskilled workers is higher in agriculture than in nonagriculture, and show that this difference is an important explanation for the relatively unproductive agrarian sectors observed in developing countries. To illustrate the argument, I simulate a simple two-sector model in which heterogeneous elasticities of substitution affect the sectoral allocation of human capital, and therefore relative productivity levels. Calibrated to match data from the United States, the model predicts sizable agricultural productivity gaps in countries where the share of highly educated workers in the labor force is low.

The third article, *Irrigation and autocracy*, is joint work with Jeanet Bentzen and Nicolai Kaarsen. In the article, we investigate how the type of agriculture a country have been dependent on historically can have a lasting impact on its political institutions. We focus on irrigated agriculture, which has traits that the resource curse literature associate with rent-seeking and poor institutional outcomes. These traits include spatial concentration, high yields, and dependence on a controllable water source.

We hypothesize that regions with a long history of irrigation-based agriculture are more likely to be autocratic today than regions with rainfed agriculture. The hypothesis is confirmed empirically. To deal with endogeneity, we use an exogenous measure of how much irrigation potentially can increase yields above the yields obtained from rainfed agriculture. The measure of irrigation potential is based on geographic an climatic factors.

At the national level, we show that areas with a higher irrigation potential are more likely to be ruled by an autocratic regime today. At the sub-national level, including country-fixed effects, we find that irrigation potential is associated with less favorable views on democracy. Last, we find that premodern societies, surveyed by ethnographers, were more likely to develop a hierarchy based on elite stratification if their agriculture was based on irrigation.

Resumé (summary in Danish)

Landbrug (inklusiv fiskeri) var fra den Neolithiske Revolution til den Industrielle Revolution den altdominerende økonomiske aktivitet i alle afkroge af verden. Men i starten af det 19. århundrede overhalede fremstillingsindustrien landbruget i Storbritannien, hvorfra den Industrielle Revolution gradvist spredtes til resten af Europa og den engelsktalende verden. Transitionen fra landbrugssamfund til industrisamfund skete samtidig med en hidtil uset acceleration i den økonomiske vækst, og, med tiden, en hidtil uset velstand. De lande, der i dag ikke har formået at gennemføre transitionen, er fortsat fattige. At forstå landbrugets rolle i økonomien er derfor væsentligt for at forstå økonomisk udvikling. Det samme gælder for den politiske udvikling. Landbrugets historiske rolle i økonomien betyder, at særinteresser i landbrugssektoren har haft en stor og varig indflydelse på landes politiske institutioner.

Denne Ph.d. afhandling bidrager til forståelsen af samspillet mellem landbruget og både økonomisk og politisk udvikling. Afhandlingen består af tre indbyrdes uafhængige forskningsartikler.

Den første artikel, *Structural transformation in the 20th century: A new database on agricultural employment shares around the world,* er motiveret af de mange spørgsmål omkring økonomisk udvikling som grundet en mangel på lange, pålidelige tidsserier for BNP, stadig er åbentstående. I artiklen argumenterer jeg for, at andelen af arbejdsstyrken beskæftiget i landbruget kan afhjælpe denne mangel. Beskæftigelsesandelen i landbruget er højt korreleret med BNP per indbygger, indeholder færre målefejl, og data er tilgængeligt i længere tidsperioder end BNP data.

Artiklen dokumenterer en database over landbrugsbeskæftigelsen i 169 lande i perioden 1900-2010 som jeg har indsamlet. I år der ikke findes data for landbrugsbeskæftiglsen, berergner jeg den ud fra urbaniseringsrater. Artiklen diskuterer også mulige anvendelser af databasen.

Den anden artikel, *Skill complementarity and the dual economy*, kredser om den teoretiske sammenhæng mellem landbrugsbeskæftigelse, national velstand og humankapital. Et væsentligt bidrag til de lave indkomstniveauer i udviklingslande kommer fra deres store landbrugssektorer, som er langt mindre produktive end resten af økonomien. I udviklede lande er der derimod ingen større forskelle mellem sektorernes produktivitetsniveauer. I artiklen viser

jeg empirisk, at substitutionselasticiteten mellem højt- og lavtuddannet arbejdskraft er større i landbruget end i resten af økonomien, og argumenterer for, at den forskel er en afgørende forklaring på den relativt uproduktive landbrugssektor i udviklingslandene. For at illustrere argumentet simulerer jeg en simpel to-sektor model hvori forskellige substitutionselasticiteter i de to sektorer påvirker allokeringen af humankapital, og følgeligt de relative produktivitetsniveauer. Modellen forudsiger store produktivitetsforskelle mellem sektorerne i lande med relativt få højtuddannede når dens parametre er kalibreret til at passe med amerikanske data.

Den tredje artikel, *Irrigation and autocracy*, er skrevet i samarbejde med Jeanet Bentzen and Nicolai Kaarsen. I artiklen viser vi, at den form for landbrug, der historisk har været praktiseret i et land, kan have en varig inflydelse på landets politiske institutioner. Fokus er på landbrug baseret på overrisling, en produktionsform som har lighedspunkter med olie og andre naturressourcer, der ofte kædes sammen med kleptokrati og udemokratiske institutioner. Lighedspunkterne omfatter geografisk koncentration, højt afkast, og afhængighed af en kontrollerbar ressource: vand fra en flod eller sø. Vores hypotese er, at regioner, der i århundreder har været afhængig af overrisling er mere autoritære end regioner, hvor landbruget har været baseret på nedbør. Vi bekræfter hypotesen empirisk. For at håndtere mulige endogeneitetsproblemer, anvender vi et eksogent mål for hvor meget overrisling potentielt kan øge mængden af afgrøder. Målet er baseret på geografiske og og klimatiske faktorer.

Resultaterne viser, at lande med højt overrislingspotentiale har en større sandsynlighed for at være styret af autoritære regimer. På sub-nationalt niveau har personer, bosiddende i regioner med højt overrislingspotentiale, et mindre favorablet syn på demokrati end personer, bosiddende i andre regioner af samme land. Endelig viser vores resultater, at præ-moderne samfund, undersøgt af etnografer, i højere grad udviklede et hierarki baseret på ejerskab af jord hvis de var afhængige af overrisling i landbruget.

Structural transformation in the 20th century: A new database on agricultural employment around the world

Asger Moll Wingender

Abstract

Many empirical questions about economic growth and development are left open due to the lack of long time series of reliable GDP estimates. The share of the labor force employed in agriculture can fill this gap. Agricultural employment shares are highly correlated with GDP per capita, less prone to measurement errors, and data are available for longer periods than existing GDP estimates.

This paper describes a new database on agricultural employment covering 169 countries for the period 1900-2010. Some of the many potential uses of the data are discussed.

1 Introduction

Why are some countries rich and some countries poor? It is arguably one of the most important question in macroeconomics, and it often shows up in introductions to papers on economic growth. No answer to the question is forthcoming without a reliable yard stick for measuring income differences between countries. Gross Domestic Product (GDP) per capita is an obvious choice of yard stick, as GDP is designed to be an empirical counterpart to aggregate output in a macroeconomic production function. Indeed, the aim of an ever growing empirical literature is to explain differences in growth rates or levels of GDP using regression analysis or accounting techniques.[1]

[1] Surveys of the two literatures can be found in Barro (1996) and Caselli (2005) respectively.

GDP has its shortcomings, however. It is a statistical concept rather than an observable quantity, and extensive information on production and prices, as well as complicated statistical methods, are required to estimate GDP. Many developing countries do not have the necessary statistical capacity to do so, and their GDP estimates are consequently unreliable.[2] The unreliability is illustrated by the recent upward revisions to GDP in Ghana and Nigeria of 62 and 89 percent respectively. Both revisions followed a change of base year for the price indecies used to calculate real GDP. As discussed in Section 6.5, equally big revisions in many poor and middle income countries have been caused by base year changes for the purchasing power parities (PPPs) used in international comparisons.

Another issue is that the modern concept of GDP was not formalized until the first System of National Accounts was published by the United Nations in 1953, and many countries did not publish official GDP estimates until decades later. Historical GDP estimates do exist for some countries thanks to the valuable work of economic historians, notably Angus Maddison and other researchers affiliated with University of Groningen Growth and Development Centre (GGDC). But the lack of raw historical data on prices and production means that such GDP estimates often suffer from high margins of error, not unlike data from present day Africa.

While much has been learned from the empirical growth literature, no clear prescription for spurring growth in developing countries has emerged. It is certainly plausible that no such prescription exists. But missing and unreliable GDP data may also make it hard to distinguish useful policies from useless ones.[3]

That is the motivation behind the data collecting project underlying this paper. As an alternative to the GDP data, I have compiled a comprehensive database of agricultural employment shares for the period 1900-2010. Agricultural employment is closely related to national income. Poor countries tend to have almost the entire labor force employed in the fields, whereas agriculture is a negligible source of employment in rich countries.The database, available online, covers 169 of the 177 independent countries that had more than 250,000 inhabitants in 2010.

I use urbanization rates to extend the database to periods where no employment data are available. Agriculture is, almost by definition, a rural activity, whereas cities are more favorable

[2]See Jerven (2013) for a book-length survey of the quality of national accounts in sub-Saharan Africa.
[3]This point is forecefully made by Ciccone and Jarociński (2010).

for most other economic activities. There is a close and stable empirical relationship between agricultural employment shares and urbanization rates, and I show that this relationship can be used to accurately estimate agricultural employment shares.

Agricultural employment shares are useful as an alternative to GDP data for several reasons. First and foremost, the share of the labor force engaged in agriculture is closely related to productivity and national income through Engel's Law. A subsistence food requirement increases the consumption share of agricultural goods in countries with low productivty levels, and hence low national income. To satisfy the high relative demand for food, more workers are needed in agriculture in poor countries than in countries with high productivity levels. An alternative would be to import the required food, but poor countries rarely do so on a sufficient scale. Low income levels are therefore reflected in sectoral employment rather than international trade. Empirically, the correlation between GDP and agricultural employment is 0.9 in a cross section of 158 countries in 2000, and, as shown in Section 6, the relationship has been stable over time despite rapid globalization.[4] The link between agricultural employment and income is a well-known stylized fact of development economics, and have been analyzed extensively. Useful overviews of the literature cen be found in Gollin (2010) and Herrendorf *et al.* (2014).

Agricultural employment shares have additional advantages over GDP data. They are much simpler to measure, and consequently less prone to measurement errors. Moreover, governments have usually carried out censuses or labor force surveys before they were able to accurately calculate GDP, or before GDP was even invented. Agricultural employment shares are, for instance, readily available for a number of countries from the 19th century and onwards. Examples are shown in Table 1.

The present study is not the first to be motivated by lacking and uncertain GDP estimates. Other researchers have looked for alternative income measures for the same reasons. Chen and Nordhaus (2011, 2014) and Henderson *et al.* (2012) use the intensity of night lights measured from space by satellites as a proxy for GDP. IMF (2006) use growth in electricity consumption to show that GDP growth in Jamaica was probably 3.1 percent per annum from 1991-2000

[4]Sources: Penn World Table 8.0 compiled by Feenstra *et al.* (2013), and the agricultural employment share data documented in this paper.

Table 1: Earliest census with employment data

Europe and North America		Other regions	
Country	**Year**	**Country**	**Year**
Finland	1774	Brazil	1872
Iceland	1801	Japan	1872
Norway	1801	Argentina	1895
United States	1820	Mexico	1900
United Kingdom	1841	India	1901
Belgium	1846	Taiwan	1905
Netherlands	1849	Indonesia	1905
Denmark	1850	Egypt	1907
France	1856	South Africa	1911

Sources: Mitchell (1993, 1998a,b), Minnesota Population Center (2008).

rather than the official estimate of 0.3 percent. Young (2012) shows that the living standards in sub-Saharan Africa, according to consumption data from the Demographic and Health surveys, have grown by three-and-a-half to four times faster than GDP per capita, indicating that GDP may be underestimated. Consistent with this result, I show in Section 6 that GDP in sub-Saharan Africa also appears to be underestimated when it is compared to the region's falling agricultural employment shares. To demonstrate that it is the African employment data that give the more accurate picture of income levels, I show that income levels predicted by lights from space correspond to the ones implied by agricultural employment shares rather than the official GDP estimates. Lights data are not available before 1992, but it seems reasonable to assume that result would be similar in earlier periods if data had existed.

Other cases of measurement errors are also visible when comparing the GDP data to agricultural employment shares. An example is the well-know overestimation of GDP in the USSR and Eastern Europe during communism. To go beyond case studies, I show in Section 6.5 that agricultural employment data can predict revisions to GDP following changes of base year for the PPP calculations. By implication, agricultural employment shares contain information on true income levels not fully reflected in the PPP adjusted GDP data.

This paper is mostly concerned with the relationship between agricultural employment and national income. But beyond being an alternative to GDP in, *e.g.*, cross country growth regressions, agricultural employment shares are useful for studying many issues not necessarily related to national income. Changed sectoral employment patterns may, for instance, affect fertility, mortality, institutions, and cultural and social norms. The database can also be used to test theoretical models of structural change, investigate the spread of industrialization, or to study the mechanics of dual economies (*i.e.*, economies where large unproductive agricultural sectors coexists alongside small and productive modern sectors). I leave these possibilities as topics for future research.

The paper is structured as follows. The theoretical and empirical links between agricultural employment and GDP are reviewed in Section 2, and measurement errors in the two variables are discussed. The sources of employment data are described in Section 3. There are a number of existing databases, notably the ones maintained by The International Labor Organization (ILO), GGDC, Oxford Latin American Economic History Database, OECD, and the International Historical Statistics by Mitchell (1993, 1998a,b). I merge these databases, and extend the resulting data set with information from numerous other sources, including data collected from national statistical offices, various issues of the Yearbook of the League of Nations, and research by economic historians.

Urbanization data are for most countries available in earlier periods than employment data. In Section 4, I describe how I use urbanization rates to estimate agricultural employment in periods when employment is unobserved. The coverage of the resulting data set is described in Section 5, and, in section 6, I compare the evolution of agricultural employment in the 20th century to the evolution of GDP per capita. Section 7 concludes by discussing potential uses of the database, and avenues for further research.

2 Agricultural employment and national income

The rationale for using agricultural employment shares to study economic development, made in the introduction, is spelled out in further details in this section. Agriculture (including fishing) was from the onset of the Neolithic Revolution to the eve of the Industrial Revolution the dominant sector around the globe. By the early 19th century, manufacturing had overtaken agriculture in the United Kingdom, from where the Industrial Revolution gradually spread to other parts of Europe and the English speaking world, albeit delayed by almost a century. The transition out of agriculture was accompanied by economic growth unprecedented in human history. Productivity increases outpaced fertility to an extent that fewer workers in the fields were needed to feed the population.

This development can be formalized in a very simple model. Let preferences be of the Stone-Geary variety, such that the utility function of the representative individual takes the form:

$$u\left(c_a, c_n\right) = \left\{ \begin{array}{cc} c_a & if\ c_a \leq \bar{c}_a \\ \ln\left(c_n\right) + \bar{c}_a & if\ c_a > \bar{c}_a \end{array} \right\},$$

where c_a is consumption of agricultural goods (food), and c_n is consumption of nonagricultural goods.[5] An extreme version of Engel's Law holds in this formulation of preferences. Consumers only care about their calorie intake when food consumption is below the satiation point $\bar{c}_a$. Above the satiation point, only nonagricultural goods increase utility.

Labor is the only input in production in the two sectors, and output is proportional to a common productivity level Z, which include technology, physical capital, human capital etc. Agricultural production per capita is consequently given by $y_a = Z \cdot AES$, where AES is the agricultural employment share. Nonagricultural production per capita is similarly given by $y_n = Z \cdot (1 - AES)$.

Let the economy be closed such that $c_a = y_a$. It follows that $AES = \min\left\{\frac{\bar{c}_a}{Z}, 1\right\}$, so countries with low productivity levels have large fractions of their workforce employed in agriculture. The productivity level, Z, is the only source of possible variation in aggregate income across countries, and agricultural employment shares are therefore proportional to GDP per capita.

The reality is, of course, infinitely more complicated than the model above. But the relationship between agricultural employment and income is also a feature of more realistic models. Recent examples include Lucas (2009), Lagakos and Waugh (2013), Gollin and Rogerson (2014) and Wingender (2014a).

It is no coincidence that theoretical two-sector models predict a high correlation between agricultural employment shares and income. They are build to match that relationship, as it

[5] This formulation of preferences is used in Laitner et al (2000) and Gollin et al (2002).

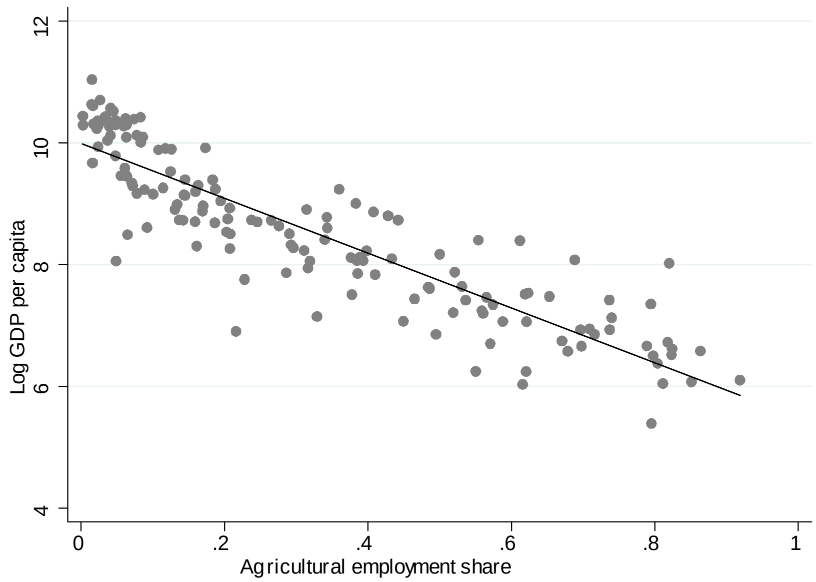

Figure 1: Agricultural employment shares and log GDP per capita 2000

is one of the most robust stylized empirical facts of economic development. It is illustrated in Figure 1, which shows log GDP per capita as a function of the agricultural employment share for a cross section of countries.

The regression line in Figure 1 has an R^2 of 0.8, and as shown in Section 6, the goodness of fit is similar in earlier periods. While the observed relationship between GDP and agricultural employment is close, it is not perfect due to measurement errors, and errors introduced by the simplicity of the model. I discuss errors in details in the next two subsections. One conclusion that emerges is that measurement errors in GDP, while hard to quantify, are likely to be substantial. The implication is that agricultural employment shares are even better predictors of unobserved true income than of observed GDP per capita.

2.1 Measurement errors

GDP is a complex statistical concept. To compute GDP, detailed statistics on production and prices are required, as well as a sizeable number of statisticians and computers to process the raw data. Neither are available in developing countries. Raw data are often non-existing, as data collection is costly, and little is known about economic activity in the large informal sector. Furthermore, limited resources are allocated to process the raw data that do exist. Jerven (2013) describes how one single person in the Central Statistical Office in Zambia was responsible for calculating all the income and growth statistics when he visited in the end of the 2000s. Visits by Jerven to other statistical offices in Sub-Saharan countries showed that Zambia is by no means unique in this respect.

Lack of data on prices is especially a worry. The recent large revisions to GDP in Ghana and Nigeria, mentioned in the Introduction, were caused by changes in the national base year used to calculate real GDP in constant prices. Both countries changed their base year to 2008, from 1993 in Ghana and 1990 in Nigeria. GDP calculated using constant prices is biased if relative prices move.[6] Price movements are often dramatic in economies where structural change happens quickly, as in Ghana and Nigeria, and the measurement error accumulates the further in time from the base year GDP is estimated.

Major GDP revisions following base year changes are no longer common in the developed world where chain-weighting is used to calculate real GDP. Chain-weighting requires detailed annual data on the price structure of the economy, and the method is not feasible in developing countries where price surveys are not carried out on a regular basis. The constant price approach is used instead. But unlike Ghana and Nigeria, many developing countries still use base years from the 1990s or 1980s, with huge implications for the accuracy of their official estimates of real GDP.

GDP levels need to be adjusted for differences in national prices to be comparable across countries. To this end, most researchers use PPP adjustment factors published by the International Comparison Program (ICP). The PPPs are calculated in a base year, and extrapolated using national price indecies. Changes in base year for the PPPs often cause significant revisions to relative GDP levels for the same reason as changes of base year in the national price data. Moreover, 22 countries did not submit price data for one or more component of the national accounts in the 2011 round of the ICP program, and their PPPs therefore contain imputed or estimated values. I discuss PPPs in further details in Section 6.5 where I show that agricultural employment shares can be used to detect measurement errors in the PPPs.

[6] This is known as the Gershenkron effect. The sensitivity of GDP to the choice of base year is explained in details in Nuxoll (1994).

Historical GDP data suffer from many of the same problems as GDP data from developing countries today. Countries that are currently developed, were relatively poor a century ago, and did not systematically collect data on production and prices. Moreover, the concept of GDP was developed in the middle of the 20th century, and adopted decades later by many countries. Data collection in earlier periods was not aimed at constructing GDP, and historical estimates of GDP therefore contain a mixture of actual observations, estimates, and guesswork.

Knowledge about prices prior to World War II is, for instance, limited in all but a few countries. As in developing countries today, historical GDP numbers are based on constant prices with distant base years rather than chain-weighting. An exception is the United States. When the Bureau of Economic Analysis in the United States recalculated the official GDP estimates using chain weights rather than constant prices, the average annual growth rate between 1929 and 1950 increased from 2.6 percent to 3.5 percent. By implication, the initial level of GDP was lower. A consequence of the revision is, as Maddison (2003) points out, that labor productivity in the United States was lower than in the United Kingdom in 1913. That amounts to a major reinterpretation of economic history. It is, however, not clear how much the GDP level in the United Kingdom would change if it was recalculated using chain weights, so the comparison makes little sense.

Many other criticisms have been raised against GDP. Nordhaus (1996) argues that the gains from technological breakthroughs are not fully captured by GDP, and gives lighting technology as an example. Other authors complain that both levels and growth rates of GDP differ widely across data sources (*e.g.*, Maddison (2010), Penn World Tables, World Development Indicators or national statistics offices), and even from update to update of a given data source.[7] For example, Ciccone and Jarociński (2010) demonstrate that the Penn World Table version 6.2 income estimates leads to substantial changes regarding the role of government, international trade, demography, and geography than the income estimates in version 6.1.

Agricultural employment is an observable quantity that is relatively easy to define and measure. The measurement problem in employment data is consequently smaller than in GDP data. Of course, measurement errors are still present in the employment data. Census data

[7] *E.g.*, Breton (2012), Johnson *et al.* (2013), Jerven (2013) and Deaton and Aten (2014).

may be incomplete, and surveys unrepresentative. But such measurement errors are usually easy to identify by looking at the meta data, which state if some regions or population groups (*e.g.*, self employed or women) are omitted. Such observations can in practice be adjusted or discarded, depending on the nature of the problem.

2.2 Model misspecification errors

Even with accurate measurement, the link between agricultural employment and income is unlikely to be perfect. It breaks down when the national income level is sufficiently high, as rich countries continue to grow after the share of workers engaged in agriculture has fallen to almost zero. Present day differences between agricultural employment shares in Germany, Sweden and the United Kingdom tell us little about relative income in the three countries. But the negligible agricultural employment shares in the three countries tell us that they have fully completed the transition out of agriculture, which an important characteristic when studying comparative development.

International trade may alter the link between agriculture and national income, as trade makes it possible for poor countries to fulfill their subsistence needs by exhanging nonagricultural goods for food on the international markets. They will use this option if they have a comparative advantage in nonagriculture, if transportation costs are sufficiently low, and if the right kind of trade policies are in place. Whether that is the case, and whether international trade have changed the relationship between income and agricultural employment shares over time are consequently empirical questions. There is some evidence that developing countries increasingly tend to be net importers of food, but the traded quantities are not substantial: Sub-Saharan Africa, the least self-sufficient region in the world, produce agricultural goods that covers 85-90 percent of the calorie intake of its population.[8] Moreover, as I show in Section 6, the relationship between measured GDP and agricultural employment shares has actually been stable over the last century.

While international trade do not introduce any systematic errors, it may exacerbate country specific idiosyncrasies. A country with a low population density, and plenty of fertile land is

[8] Source: FAO (2012).

likely to have many people employed in agriculture if it is able to sell crops on the international markets. The United States was an example of this until the second half of the 20th century.

Very unequal societies, where the elite depend on resource rents may also be able to attain relatively high levels of national income even if the majority of the population is employed in subsistence farming. Equatorial Guinea, one of the biggest oil producers in Africa, is an example. It has an agricultural employment share of roughly 60 percent, but, according to some international comparisons, a GDP per capita comparable to Southern Europe.[9] It is arguably the agricultural employment share that gives the most accurate picture of development in Equatorial Guinea.

The sources of error described above should be kept in mind when employment data are used to analyze economic development and structural change, but they do not change the fact that agricultural employment shares are powerful predictors of national income. On that note, the remainder of this paper is devoted to a description of the database on agricultural employment shares I have compiled.

3 Employment data

I outline the available sources of agricultural employment data, and the strategy I use to merge them, in this section. The data appendix provide more details, as does the additional data documentation in Wingender (2014b).

I limit the database to countries that were fully independent, and had more than 250,000 inhabitants in 2010. Some of these were parts of larger entities in the earlier periods (*e.g.*, the USSR and Yugoslavia), but I report agricultural employment shares based on present day borders. Consistent with many of the data sources I use, individuals employed in fishing, hunting or forestry are categorized as agricultural workers.

The raw data for calculating agricultural employment shares mstly come from national population censuses, household or labor force surveys. Collecting these from national statistics

[9]Source: World Development Indicators. Penn World Table 8.0 puts the GDP per capita level of Equatorial Guinea substantially lower, and roughly equal to that of Columbia. But it is stil substantially higher than what indicated by the agricultural employment share.

Table 2: Employment databases

Database	Coverage	Period	Type
FAO	World	1980-present	Observed and estimates
GGDC EU KLEMS	Europe	1950-present	Observed and estimates
GGDC Africa Sector Database	Africa	1960-present	Observed and estimates
GGDC 10-sector Database	Asia, Latin America and OECD	1990-present	Observed
ILO (KLIM and Laborstat)	World	1969-present	Observed
International Historical Statistics*	World	1800-present	Observed
OECD	OECD	1990-present	Observed
Oxford Latin America Economic History Database	Latin America	1870-present	Observed

*Notes: *Mitchell (1993, 1998a,b)*

offices is an immense task. Fortunately, much of the information is already provided by the international databases listed in Table 2. I use data from all of them. The exception is the database provided by the Food and Agriculture Organization of the United Nations (FAO) for reasons explained below.

The databases do not contain observations from all countries in the regions they cover, nor do they provide observations for all years. When information is missing (or unreliable), I augment the data with information from other sources. For the recent decades, that is mostly done by tracking down the numbers on the websites of the respective national statistical offices. I have done so for Albania, Angola, Brunei Darussalam, Cabo Verde, Chad, Côte d'Ivoire, Lao, Lebanon, Lesotho, Kosovo, Madagascar, Maldives, Nepal, Nigeria, Solomon Islands, Timor-Leste, Viet Nam and Zimbabwe. Further, I have calculated agricultural employment shares from micro-level census data obtained from the IPUMS-International database for Brazil, Fiji, Guinea, Haiti, Peru, South Sudan, Uganda, Burkina Faso and Uruguay.[10] Data for the USSR republics are obtained from Easterly and Fischer (1995). For years prior to World War II, I rely on various issues of the Statistical Yearbook of the League of Nations, additional historical census data, and research by economic historians. The full list of sources is available in the data appendix.

[10] The database is compiled by Sobek *et al.* (2013).

3.1 Cleaning and merging the databases

Two data source sometimes disagree on the level of agricultural employment for a given country in a given year. The result of a labor force survey may, for instance, differ from the result of a census. Sometimes the reason for the disagreement can be found in the meta data. A common cause of discrepancies is differences in geographical coverage. Labor force surveys are in some cases only carried out in urban areas, and they consequently understate agricultural employment. The same is true when self-employed are excluded from the survey. Such observations, which the meta data allows me to identify as inconsistent with the remaining data, are removed from the data set. Observations that are clearly outliers are similarly removed if the meta data are missing.

Another cause of discrepancies is that some data sources report estimated rather than observed agricultural employment shares. As a rule of thumb, I discard all observations that are based on extrapolation or model estimates, even if no actual observation is available.[11] I do so, as analyses based on such data risk getting into circular arguments, where assumptions about economic development are tested using data generated from assumptions about economic development.

In practice, I drop a number of observations in the GGDC Africa Sector Database that are estimated based on aggregate productivity growth as implied by the national accounts. A large number of observations in the FAO data set are extrapolated based on a fitted logistic growth path. Moreover, data for a number of countries in the FAO database are pure estimates, as the do not participate in the FAO agricultural census program, and no other sources of employment data exists.[12] It is in the data set not possible to distinguish actual observations from estimates, and I therefore disregard the FAO data set completely.

[11] I make one exception by including the EU-KLEMS data set, which are underpinned by sufficiently many actual observations to be considered accurate. Hungary and Austria are exceptions, and EU-KLEMS is not used for these two countries.

[12] The accuracy of these estimates are questionable. For example, FAO reports an agricultural employment share of around 70 percent in Djibouti. Yet, roughly 75 percent of the population of Djibouti resides in the capital, Djibouti city, and an establishment survey show that there were only 1,690 agricultural holdings in the country in 2006/2007.

The remaining observations are broadly in agreement about agricultural employment, and the different data sources can therefore be merged seamlessly. The few exceptions where additional adjustments are needed are described in Wingender (2014b).

4 Extending the data set using urbanization rates

Most countries currently collect employment data, but that has not always been the case. The number of countries with employment data is around 90 in the 1950s, down from 169 in the 2000s. Fortunately, urbanization rates can be used to estimate agricultural employment shares in periods when no employment data exist. Agriculture is, almost by definition, a rural activity, whereas cities are more favorable for most other economic activities. There are exceptions to this rule, such as mining, but we should nonetheless expect urbanization to be lower in countries with a high employment share in agriculture.

The expectation is confirmed by the data. Figure 2 shows the close empirical relationship between agricultural employment shares and urbanization in 1970, one of the earliest year with a substantial number of observations of both variables. The estimated parameters for the regression line are shown in Table 3. The table also reports coefficients for regressions made for a pooled sample of all years, as well as for the individual years 1950 and 2000. The estimates seem plausible, as they imply that a country with little urbanization will have all of its population engaged in agriculture ($AES_{i,t} = \frac{-0.81}{0.82} = 0.99$ in the pooled sample). Moreover, the estimated intercepts and slopes are remarkably constant over time, which is reassuring when the relationship is used to predict agricultural employment shares out of sample. In the remainder of this section, I describe the methodology and data sources I use to accomplish this task.

4.1 Urbanization: Sources and definitions

Censuses not only provide information on the total size if the population, but also its location, thus allowing urbanization rates to be calculated. The United Nations has collected census

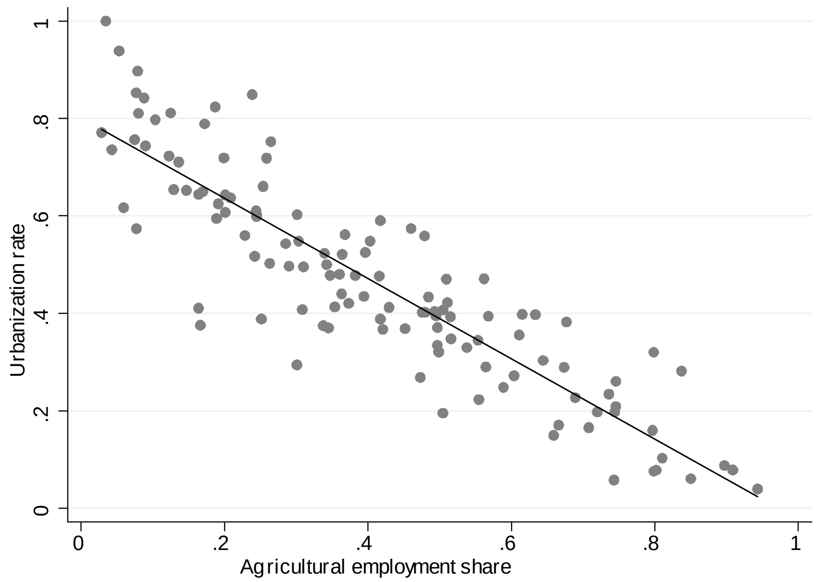

Figure 2: Urbanization and agricultural employment 1970

Table 3: Urbanization and agricultural employment

Sample	Pooled sample	2000	1970	1950
Intercept	0.81 (0.00)	0.80 (0.02)	0.80 (0.02)	0.82 (0.03)
Slope (coefficient on AES)	−0.82 (0.00)	−0.80 (0.04)	−0.82 (0.04)	−0.83 (0.06)
R^2	0.78	0.73	0.79	0.74
Observations	8,689	146	120	77

Notes: The dependent variable is the urbanization rate.

data on urbanization from all the member countries back to 1950.[13] Additional information from sample surveys and from estimates, made either by national governments or the United Nations, are used if no census data are available.[14]

The urbanization rates are not comparable across countries as the definition of urban varies. Most countries define urban areas in terms of the number of people living in a given agglomeration, but the cut-off ranges from just 200 in Denmark to 10,000 in Italy and Senegal. Some countries also require agglomerations to be primarily non-agricultural in terms of employment, to have access to electricity, or to be the administrative centre of a municipality before they are considered urban in the statistics.

The United Nations make no attempt to harmonize definitions, as they argue that a harmonization is unlikely to increase comparability.[15] A settlement of 5,000 people are often decidedly rural in terms of economic activity in China and India, whereas it is likely to be a centre of commerce and industry in Europe. Bairoch (1991) similarly argue that small towns in Europe historically have been peculiar in a global comparison due to the limited agricultural activity of their inhabitants. He offers Western Nigeria as an example of the opposite. In the 1952 census, roughly one third of the males living in cities with populations between 5,000 and 80,000 were engaged in agriculture. As it will be shown below, the estimation strategy I use is not affected by differences in definitions of urban.

Prior to 1950, I urban population data from Eggimann (1999) for Africa, Asia and Latin America, and from the USSR republics from Lewis *et al.* (1976). With a few exceptions, Countries in Western Europe, North America and Oceania have actual employment data back to the 19th century, and urbanization data are therefore not needed. Eggimann (1999) provides population estimates for named cities, not urbanization rates for entire countries. To calculate the latter, knowledge of total populations is needed. I obtain population data from International

[13] United Nations (2012a).

[14] If no obervations are available in 1950, extrapolation is used to extend the data set backwards. For about 10 percent of the countries, the extrapolation is applied to a longer period than decade. Most of these countries are island nations with populations too small to be included in the data set of this paper (*e.g.*, Palau, Vanatu, and Tuvalu).

[15] United Nations (2012b).

Historical Statistics augmented by various historical census data from other sources.[16]

The resulting urbanization rates are defined differently than the urbanization rates in the United Nations (2012a) data from 1950 and onwards. I use the overlapping observations in 1950 and Zipf's law to adjust the pre-1950 data to conform to the post-1950 definition (which differ from country to country).[17]

4.2 Estimation strategy

It is useful to illustrate where the empirical relationship between urbanization and agricultural employment comes from before the strategy for estimating agricultural employment out of sample is reviewed. The starting point is the following accounting equation for the labor force engaged in agriculture:

$$L_{i,t}^{A} = AES_{i,t}^{u} e_{i,t}^{u} U_{i,t} + AES_{i,t}^{r} e_{i,t}^{r} \left(P_{i,t} - U_{i,t}\right), \tag{1}$$

where $L_{i,t}^{A}$ is the number of individuals engaged in agriculture in country i in period t, $P_{i,t}$ is the total population, and $U_{i,t}$ is the number of individuals living in urban areas according to the national definition. $AES_{i,t}^{u}$ and $e_{i,t}^{u}$ are the agricultural employment share and the employment rate in urban areas. $AES_{i,t}^{r}$ and $e_{i,t}^{r}$ are the similar variables for rural areas.

Equation (1) can be rewritten to yield an expression for the aggregate agricultural employment share, $AES = \frac{L^A}{L}$:

$$AES_{i,t} = \left\{ \left(AES_{i,t}^{u} e_{i,t}^{u} - AES_{i,t}^{r} e_{i,t}^{r} \right) U_{i,t} + AES_{i,t}^{r} e_{i,t}^{r} P_{i,t} \right\} \frac{1}{L_{i,t}}.$$

[16]These include Lewis *et al.* (1976) for the USSR, McGee (1964) for Malaysia, Karpat (1985) for the Ottoman Empire, and McEvedy *et al.* (1978) for Indonesia and the countries on the Indian subcontinent. For Africa, I rely on population estimates made by Manning (2010), which correct known errors in the colonial records.

[17]Zipf (1941). The adjustments to the urbanization series are done as follows. Let u_x denote the urbanization rate where the cut-off for urban is cities with x inhabitants. Let u_y be defined in the same way. Zipf's law states that cities are distributed according to a power law. Power laws are scale invariant, and $\frac{u_x}{u_y}$ is consequently constant and independent of how the aggregate urban population evolves over time. It follows that $u_{x,t} = u_{y,t} \frac{u_{x,T}}{u_{y,T}}$, where t indexes time, and T is an arbitrary period where the two series overlap. This relationship allows $u_{x,t}$ to be calculated in periods where only $u_{y,t}$ is available, and vice versa.

Define the urbanization rate as $UR_{i,t} = \frac{U_{i,t}}{P_{i,t}}$, and let $e_{i,t}$ be the aggregate employment rate. It follows that:

$$AES_{i,t} = \left(AES^u_{i,t} \frac{e^u_{i,t}}{e_{i,t}} - AES^r_{i,t} \frac{e^r_{i,t}}{e_{i,t}} \right) UR_{i,t} + AES^r_{i,t} \frac{e^r_{i,t}}{e_{i,t}}.$$

This equation can be rearranged to yield the estimation equation used in Figure 2 and in Table 3:

$$UR_{i,t} = \beta_0 + \beta_1 AES_{i,t} + \varepsilon_{i,t} \tag{2}$$

Estimates of the two parameters β_0 and β_1 are are provided in Table 3 in the introduction to this section. The error term $\varepsilon_{i,t}$ contains idiosyncracies in agricultural employment shares and participation rates in rural and urban areas uncorrelated with the *aggregate* agricultural employment share. The idiosyncrasies are, in part, driven by differences in the national definitions of urban and rural populations. The agricultural employment share in urban areas will, for example, be larger when the towns defined as urban are smaller.

The uncorrelatedness of $\varepsilon_{i,t}$ is not sufficient to estimate $AES_{i,t}$ out of sample. Additional assumptions about the error term $\varepsilon_{i,t}$ are needed.

Growth rates in the agricultural employment share are proportional to growth in the urbanization rate if the error term $\varepsilon_{i,t}$ is assumed to be time invariant ($\varepsilon_{i,t} = \varepsilon_i$). The same is true for expected growth rates if $\varepsilon_{i,t}$ is i.i.d. However, both assumptions are unrealistic, since the error term $\varepsilon_{i,t}$ depends on employment rates and agricultural employment in urban and rural areas. They are behavioral variables that are likely to evolve over time, but only very gradually.

Instead, I assume that assume that the ratio $\frac{\varepsilon_{i,t}}{UR_{i,t}}$ is constant and equal to $\frac{\varepsilon_{i,T}}{UR_{i,T}}$ in periods $t < T$, where T is the earliest year with employment data, and thus the earliest year for which Equation (2) can be estimated. There are several reasons for choosing this specification. It is consistent with slow-moving behavioral variables, and the movement of the resiudal is toward zero, which is reasonable if countries that are closer to an undeveloped steady state are more likely to be identical in terms of urbanization and agricultural employment than more developed countries. The variance of the error term should thus be lower when urbanization is lower. Furthermore, the assumption that $\frac{\varepsilon_{i,t}}{UR_{i,t}} = \frac{\varepsilon_{i,T}}{UR_{i,T}}$ for $t < T$ is essentially a way to impose mean reversion in the errors, since urbanization rates generally are increasing over time. Errors will have this property if there are measurement errors in the employment data in year T. Lastly, the assumption implies that $\gamma > 0$ in the following regression:

$$|\varepsilon_{i,t}| = \gamma UR_{i,t} + country\ fixed\ effects + error$$

That is indeed the case. $\gamma = 0.38$ with a t-value of 10.87.[18]

The assumption that $\frac{\varepsilon_{i,t}}{UR_{i,t}} = \frac{\varepsilon_{i,T}}{UR_{i,T}}$ is also practical when estimating the agricultural employment share out of sample. Substituting the assumption into Equation (2) yields:

$$\begin{aligned} UR_{i,t} &= \beta_0 + \beta_1 AES_{i,t} + UR_{i,t}\frac{\varepsilon_{i,T}}{UR_{i,T}} \\ &\iff UR_{i,t}\left(1 - \frac{\varepsilon_{i,T}}{UR_{i,T}}\right) = \beta_0 + \beta_1 AES_{i,t} \\ &\iff UR_{i,t}\frac{\widehat{UR}_{i,T}}{UR_{i,T}} = \beta_0 + \beta_1 AES_{i,t}\ , \end{aligned}$$

where $\widehat{UR}_{i,T}$ is the predicted value of the urbanization rate in period T obtained from the regression in Equation (2). The entire term $UR_{i,t}\frac{\widehat{UR}_{i,T}}{UR_{i,T}}$ corresponds to urbanization in period t, or $\widehat{UR}_{i,t}$.Differences in the national definition of urban are contained in the error terms of Equation (2), and the predicted urbanization rate can therefore be interpreted as being harmonized according to a definition that depends on the aggregate agricultural employment share.

The agricultural employment share in period t can be calculated as:

$$AES_{i,t} = \frac{\widehat{UR}_{i,t} - \beta_0}{\beta_1},\ t < T \tag{3}$$

I use this equation along with the pooled estimates of the parameters, *i.e.*, $\beta_0 = 0.81$ and $\beta_1 = -0.82$, to obtain values of $AES_{i,t}$ in years prior to the year where actual employment data become available. Some countries have not yet published data on agricultural employment

[18] Estimated for the full sample. The results are similar when the sample is limited to developing countries, and when the squared residuals are used as dependent variable in the regression.

shares in the last few years of the sample period, so a similar approach is used to estimate agricultural employment shares in these years.

4.3 Precision

To test the accuracy of the methodology to estimate AES, I set the starting year $T = 2000$ for all countries. I then derive the predicted agricultural employment shares for 1970 and 1950, and compare the predictions to the observed agricultural employment shares by estimating the following regressions:

$$AES_{i,t} = \lambda_1 \widehat{AES}_{i,t} + \eta_{i,t}, \tag{4}$$

and

$$AES_{i,2000} - AES_{i,t} = \lambda_2 \left(\widehat{AES}_{i,2000} - \widehat{AES}_{i,t} \right) + \mu_{i,t}, \tag{5}$$

for $t = 1950, 1970$. The estimated parameters should be $\lambda_1 = \lambda_2 = 1$ if the predicted agricultural employment shares are unbiased, and the prediction errors, $\eta_{i,t}$ and $\mu_{i,t}$, should be small if the estimates are accurate. The results are shown in Table 4. For $t = 1950$, both estimated parameters are somewhat smaller than one, but not significantly so at a 95 percent confidence level. For $t = 1970$, λ_1 and λ_2 are are significantly smaller than one in a statistical sense, but the difference does not seem substantial in the case of λ_1.

The estimate of λ_2 is 0.85, indicating that the estimated changes in agricultural employment shares may overstate the actual changes. An explanation is that idiosyncratic shocks play a larger role when the time frame is short, and the estimated λ_2 is therefore harder hit by attenuation bias. Consistent with this interpretation, the estimated λ_2 falls further when the time period is shortened, and the standard error increases despite more observations. For $t = 1980$, for instance, $\lambda_2 = 0.75$ with a standard error of 0.06. A small bias in the short run of this sort is a minor worry, as the aim of the database is to provide a measure of long run growth. Moreover, the very high R^2 indicate that the prediction errors are relatively minor. Based on the results in Table 4, I therefore consider the estimated agricultural employment shares to be accurate.

Table 4: Test of AES estimation

Year	**1950**	**1950**	**1970**	**1970**
Estimated parameter	λ_1	λ_2	λ_1	λ_2
Estimate	0.98 (0.02)	0.95 (0.03)	0.95 (0.02)	0.85 (0.04)
R^2	0.96	0.90	0.96	0.78
Observations	77	77	114	114

Notes: Results of estimating Equation (4) and (5)

5 The final data set

Three additional steps are taken to increase the coverage of the data set. First, I interpolate between observations. Census data are, for instance, usually collected once every decade, and the census year differ from country to country. I use a simple linear interpolation to fill the gaps if no other data source is available. The second step is to place an upper bound on the estimated agricultural employment shares. The highest agricultural employment share observed in a census or a survey is 0.94 (Nepal 1971). It seems unlikely that any country have exceeded that number by much in modern times, since traders, craftsmen and government administrators exist in even the most underdeveloped nations. I therefore set $AES_{i,t} = 0.95$ if the predicted values from Equation (3) are bigger than 0.95.[19] The third step is to extrapolate the agricultural employment shares backward in the eight countries where the upper bound of 0.95 is reached in the first year of observation.[20] The implicit assumption is that this group of countries are in an underdeveloped steady state. To confirm this assumption, I cross check with the urban population data in Eggimann (1999). None of the countries for which the extrapolation is made had any significant urban development in 1900.

The coverage of the final database is illustrated in Figure 3. From 1950 an onward, the database contains information on agricultural employment shares for 169 countries out of the 178 countries in the world with more than 250,000 inhabitants in 2010. The number falls to

[19] A similar boundary problem can potentially arise when the predicted $AES_{i,t}$ is close to 0. However, all countries with low employment shares in agriculture are developed at the time of measurement, and have survey or census data on AES. No estimation is therefore needed.

[20] The countries in question are Bhutan, Burundi, Lesotho, Nepal, Niger, Papua New Guinea, Rwanda and Zambia.

116 countries in the beginning of the 20th century. Most of the recent data points are based on actual employment data, whereas estimates based on urbanization rates are more prominent in the beginning of the period. All countries have at least one observation based on actual employment data.

There are about 30 countries with no data prior to 1950. They are spread evenly across the developing world. The exception is the countries on the Arab Peninsula, where no census or survey data were collected before World War II.

To track the long run growth process for more countries than what is possible in other data sets currently available to researchers is a central motivation for constructing the database. The success criterion is therefore two-fold. The database should have a broader coverage than existing data sets, and it should be an accurate yard stick of development.

Success on the first criterion can easily be judged by comparing the data availability to other data sets containing information on national income or development. By construction, my database covers more countries in more years than any of the individual sources of employment data it is based on. One of the most well-known and comprehensive data sets for analyzing national income over the long run is Angus Maddison's historical GDP data.[21] The black line in Figure 3 shows the number of countries for which Maddison provide GDP estimates.[22] It is below the number of countries in my database for all years, and my database thus compares favorably with Maddison in terms of coverage.

The comparison to Maddison's GDP data is, obviously, only relevant if the employment data are useful for analyzing income levels or economic growth. The next section evaluates my data set along this dimension.

6 The evolution of agricultural employment and GDP

The share of the labor force employed in agriculture in a country today is, as argued in Section 2, a an accurate predictor of its national income. In this section, I show that the same has

[21] Maddison (2010).

[22] There are gaps in the Maddison GDP data for many countries. I have counted years where interpolation makes it possible to fill gaps as observed when assessing the data availability in Maddison.

Figure 3: Data availability

been true historically, and, by implication, that agricultural employment shares are suitable to analyze long run trends in income. I also demonstrate that agricultural employment shares are able to correctly identify well-known measurement errors in the GDP data. My database can therefore be a useful alternative to GDP data when studying economic growth and comparative development, even in periods when GDP data are available.

6.1 Stability

To check whether the link between agricultural employment and income has been stable over time, I regress Maddison (2010) log GDP per capita on the agricultural employment shares from my database. The results are reported in Table 5 for different years. The constant term seems to be increasing slightly over time, and the coefficient on the agricultural employment share falls from -2.82 in 1900 to -3.97 in 2000.

Part of the explanation is that the sample changes over time. Data become available for more and more countries, and the sample of countries becomes more representative in terms of the stages of development. While the 1900 sample includes all the most developed nations at the time, only the United Kingdom had an agricultural employment share below one quarter.

Table 5: Agricultural employment and historical GDP estimates

	1900	1925	1950	1975	2000	2000*
Constant	9.06 (0.14)	8.86 (0.12)	9.23 (0.12)	9.55 (0.08)	9.51 (0.07)	9.18 (0.11)
Coefficient on *AES*	−2.82 (0.21)	−2.39 (0.19)	−3.06 (0.17)	−3.36 (0.14)	−3.97 (0.18)	−3.38 (0.18)
R^2	0.80	0.72	0.71	0.79	0.76	0.67
Observations	48	66	134	157	158	120

*Notes: *Countries with AES < 0.1 are excluded. The dependent variable is log GDP per capita from Maddison (2010).*

In 2000, on the other hand, 86 countries had an agricultural employment share below one quarter. The difference is illustrated in Figure 4 by the data points and regression lines for the years 1900 and 2000.

The reason why the slope and intercept of the regression change when the sample includes more highly developed countries is that countries continue to grow after the agricultural employment share has fallen to near zero. That is the case for the cloud of observations above the regression line in the upper left corner of Figure 4. To demonstrate the consequence of the regression estimates, countries with less than ten percent of the workforce employed in agriculture in 2000 are excluded from the sample in the final column of Table 5. Compared to the full sample, the intercept is lower and the slope flatter. Moreover, the regression line is no longer significantly different from the one estimated for 1900. The relationship between Maddison's GDP estimates and the agricultural employment shares therefore seems to have been fairly stable over time in countries where agriculture still plays a significant role in the economy.

6.2 Regional GDP growth

Figure 5 and 6 show the evolution of GDP per capita and agricultural employment in the 20th century for eight regions. In each region, the two variables are population weighted. Countries with missing observations in parts of the period are left out, but the subsamples are nonetheless fairly representative for the region. The exception is North Africa and the Middle East grouping, which does not cover the Arab Peninsula. The scales for agricultural employment are inverted, and adjusted such that a given value of the agricultural employment

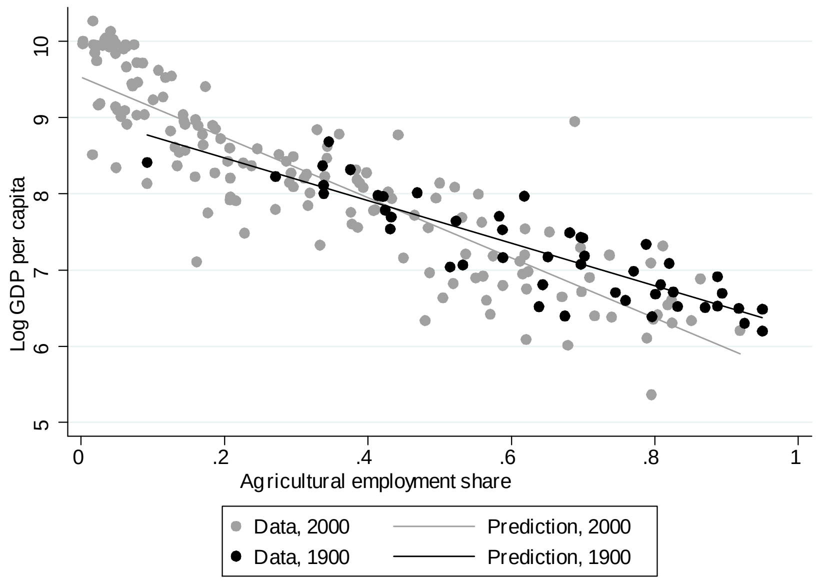

Figure 4: Agricultural employment and real GDP per capita.

share on the left hand y-axis corresponds to the predicted GDP level according to the regression for 1950 reported in Table 5.

Panel A of Figure 5 shows that GDP per capita in Western Europe closely resembles income as predicted by agricultural employment from 1900 to the 1960s. From then, GDP has outpaced the decline in the agricultural employment share. The same pattern is found in the European off-shoots (Australia, Canada, New Zealand and the United States), where the growth rates in the two variables also decoupled in the 1960s. The decoupling of GDP from agricultural employment is a sign that the economies have completed the transition out of agriculture.

Although the trend is as expected, the level of GDP per capita in the European off-shoots prior to 1960 is higher than predicted by their agricultural employment shares. The low population densities and the vast expanses of fertile land presumably account for this finding. The high land-to-labor ratios made agriculture, at a given stage of development, more attractive in the United States and in the other off-shoots than in Western Europe.

Before the fall of communism, GDP was higher than indicated by agricultural employment in the USSR and in Eastern Europe. Like the European off-shoots, USSR had a low population density, which could explain the observed pattern. Other explanations are possible, however. Output, as measured by GDP, declined markedly after the fall of communism. But electricity consumption declined much less than what should be expected given the size of the contraction, indicating that the output decline probably is exaggerated in the GDP statistics.[23] One source of inflated GDP numbers is overcounting of produced quantities, which were common in the communist era when factory managers had to reach certain production targets every year.[24] Another source of inflated GDP numbers is the price data. The heavy industries in the USSR and Eastern Europe produced large quantities of low quality goods that would have been in limited demand in a market economy. The official prices of these goods before the fall of communism are likely to have exaggerated their values. And observed market prices *after* the fall of communism, when supply was reduced and quality increased, will similarly be too high. Using either of these alternatives cause the GDP statistics overstate income levels before the end of communism, but no other price data are available to national accountants. The comparison with agricultural employment shares in Figure 5 makes the overestimation of GDP for USSR and communist Eastern Europe clearly visible.

Figure 6 shows agricultural employment shares and GDP per capita in four regions that largely consist of low and middle income countries. Japan, Singapore and South Korea are obvious exceptions, but these countries have a relatively small impact on Asia as a whole, given the large populations in China, Indonesia and on the Indian subcontinent. The scales on the y-axes are adjusted slightly from the ones in Figure 5 to make the trends in the data more visible.

GDP per capita has largely evolved as predicted by the agricultural employment share in Latin America, and in North Africa and the Middle East. The agricultural employment share in Asia, on the other hand, indicates that incomes were substantially higher in the middle of the 20th century than what is implied by GDP estimates, and that the subsequent growth miracle therefore was less dramatic. Explanation this finding is an interesting topic for further research.

[23] Eichengreen (2008).

[24] Åslund (2001).

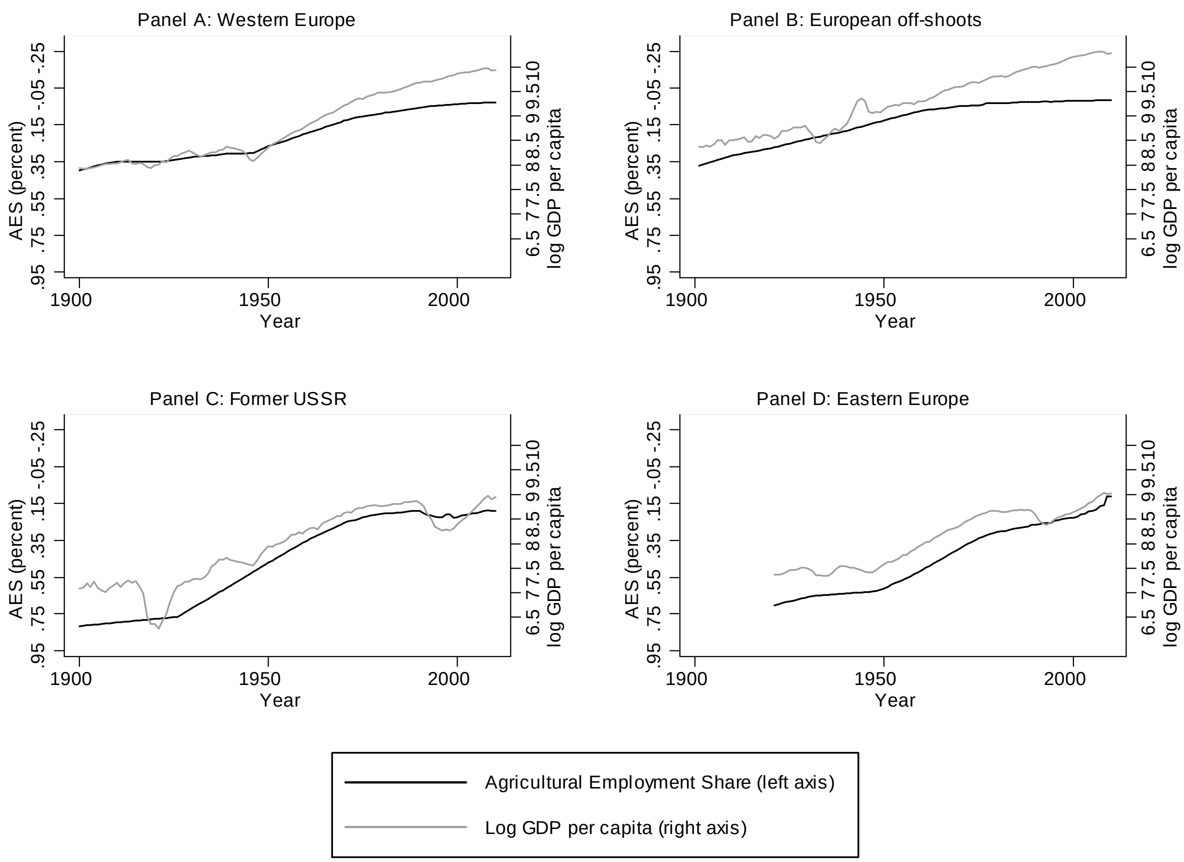

Figure 5: Long term growth in GDP/capita and the agricultural employment share (inverted scale)

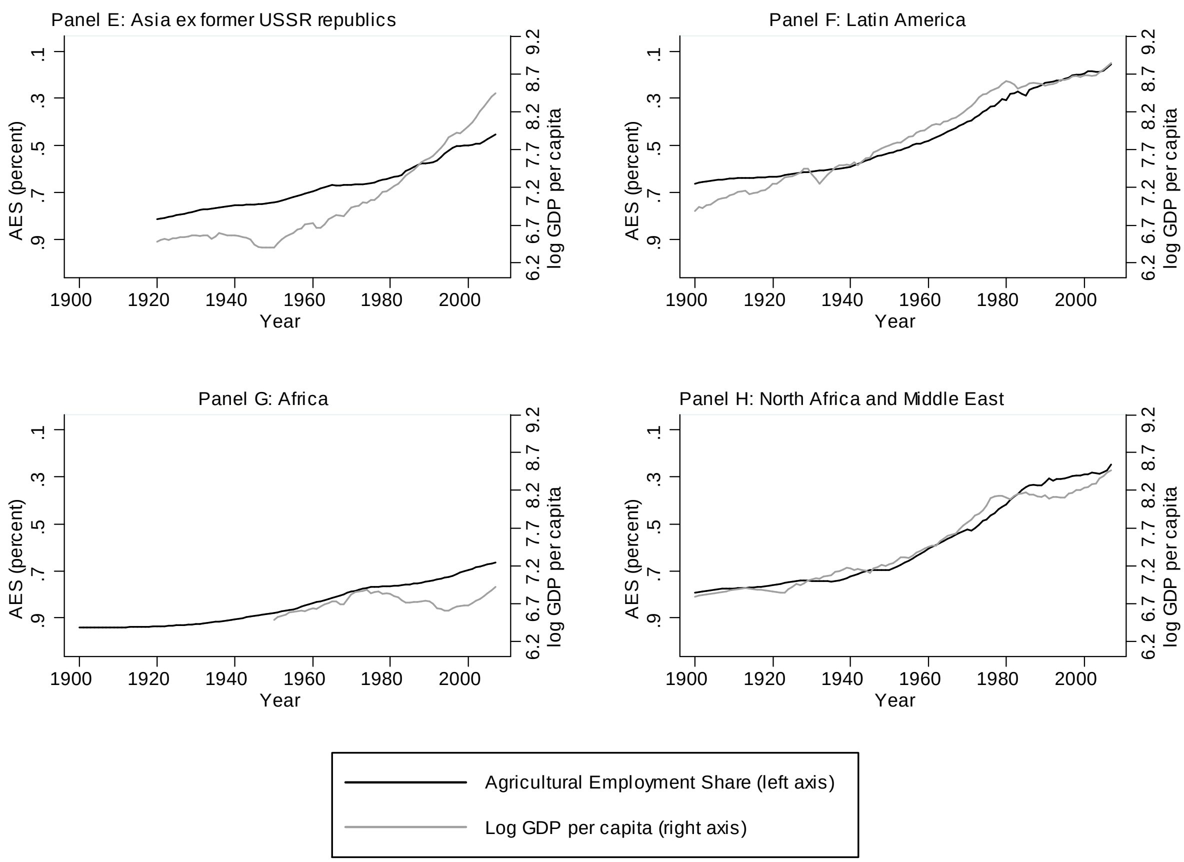

Figure 6: Long term growth in GDP/capita and the agricultural employment share (inverted scale)

Table 6: GDP bias in Africa

Explanatory variable	*AES*	Lights/capita
Constant	9.15 (0.11)	10.15 (0.16)
Coefficient on explanatory variable	−3.02 (0.27)	0.48 (0.04)
Coefficient on Africa dummy	−0.28 (0.11)	−0.25 (0.12)
R^2	0.69	0.73
Observations	115	118

Notes: The dependent variable is log GDP/capita from Maddison (2010). The light data are from Henderson et al. *(2012)*

6.3 Income in sub-Saharan Africa

The GDP estimates in sub-Saharan Africa also conflict with the observed fall in the agricultural employment share. As it can be seen in Panel G of Figure 6, the two series follow each other closely from 1950 to the 1970s. In the following to decades, GDP fell, and a sizeable gap to the income level predicted by agricultural employment and the GDP estimates emerged. Research by Young (2012) and Jerven (2013) show that GDP estimates in Africa suffer from a significant downward bias. To demonstrate that the bias account for most of the gap observed in Figure 6, I compare the income level for sub-Saharan Africa implied by agricultural employment shares to the level predicted by another proxy for income: Night lights measured from space by sattelites.

To do so, I first regress measured log GDP per capita on agricultural employment and a dummy variable for sub-Saharan Africa for the year 2000. As in the final column of Table 5, I exclude countries with less than 10 percent of the labor force employed in agriculture from the sample. The results are reported in Table 6. The coefficient on the dummy variable indicates that the measured GDP level in sub-Saharan Africa is approximately 28 percent lower than the income level predicted by agricultural employment shares.

The last column of Table 6 shows the results of a similar regression where light intensity per capita rather than agricultural employment is used as a proxy for true income. Consistent with the agricultural employment shares, the night lights imply that GDP in sub-Saharan Africa is underestimated by 25 percent.

6.4 Convergence and global inequality

The slightly different growth paths of agricultural employment shares and GDP per capita have implications for the measured income dispersion between countries. The patterns of global inequality depend on which of the two proxies for income that is used to compute them. Figure 7 shows how the standard deviations across countries of agricultural employment shares and of log GDP per capita have evolved over time. A decline in the standard deviation is known as σ-convergence.

Panel A shows convergence for the 49 countries with data available both in Maddison (2010) and in my database since 1900. The standard deviation of agricultural employment shares is rescaled to make it directly comparable to the standard deviation of log GDP per capita.[25] Both the Maddison GDP data and the agricultural employment shares imply a stable degree of global inequality in the first half of the 20th century. From then there has been σ-divergence, according to the GDP numbers, and global inequality was at an all-time high around the end of the century. By contrast, the employment data show σ-convergence.

A similar conclusion is reached when using GDP data from Penn World Tables 8.0 (Panel B, 104 countries), whereas the employment data and GDP data from the Barro-Ursua macroeconomic data set, used to study convergence by Barro (2012), are more in agreement (Panel C, 34 countries).

The difference between the two series in Panel A and B is partly driven by the downward bias in GDP data for Africa and other developing countries. The most visible sign of this is the marked σ-divergence in the Penn World Tables data relative to the σ-divergence in the Maddison data, which contain fewer countries from the developing world.

[25] I use the regression coefficient α_1 from the following regression to scale the standard deviations of agricultural employment shares: $\log(GDP/capita) = \alpha_0 + \alpha_1 AES + error$. The regression corresponds to the ones reported in Table (5), but is estimated for the pooled sample of all years. The implicit assumption is that α_1 is stable over time. The results of Table (5) suggest that the assumption is a reasonable approximation in countries where agricultural employment is still significant. Admittedly, the point estimate of α_1 has been rising (numerically) over the 20th century. While the rise is not significant in a statistical sence, it may, if it reflects an actual change in the structural relationship, cause a slight secular tendency to σ-convergence in the agricultural employment data. This potential bias strengthen the results presented in this sub-section.

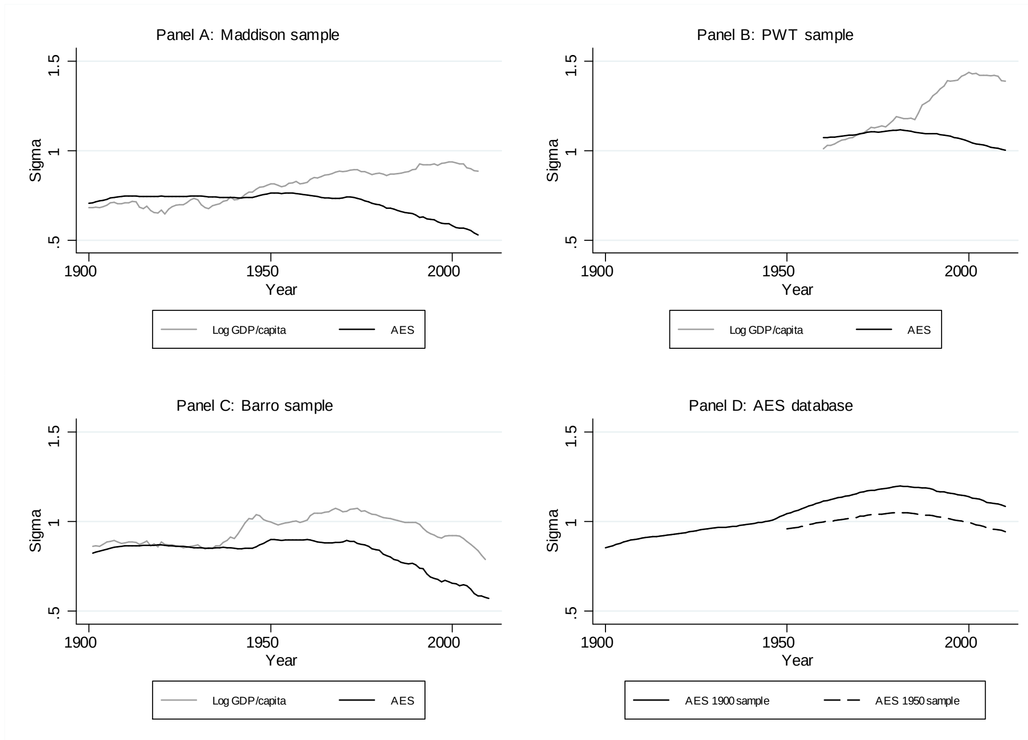

Figure 7: Sigma convergence

The σ-convergence in agricultural employment shares is also a consequence of the variable being bounded between 0 and 1. By construction, global inequality in agricultural employment shares is also bounded. Such boundedness naturally gives rise to what amounts to a global Kuznets curve for structural transformation. Inequality was low in the premodern era, where all countries had most of their labor forces employed in agriculture, and will similarly be low when all countries have completed the transition out of agriculture. Between these two extremes, differentiated timing of the transitions out of agriculture imply high degrees of inequality.

The Kuznets curve is clearly visible in Panel D of Figure 7, where the σ for the full sample of countries available in my database is shown. The 1900 sample consists of the 116 countries with data for the full period, and the 1950 sample is the 169 countries with data available from 1950 and onward. It is interesting to note that peak inequality coincide with the onset of a new era of globalization.

The presence of a Kuznets curve in agricultural employment shares shows that initially rich countries, *i.e.*, countries that had begun the the transition out of agriculture, grew faster than other countries in the first half of the 20th century. This is consistent with Unified Growth Theory, where initial conditions explain differentiated timing in the transition to modern economic growth.[26] It is, however, at odds with the "iron law" of conditional β-convergence, which states that poor countries will have faster GDP per capita growth than rich ones.

Estimating rates of conditional β-convergence is suprisingly difficult, not just because of measurement errors in GDP. The econometrics is tricky, and a consensus on the best empirical strategy has yet to emerge.[27] Estimates based on GDP data face the additional problem of limited numbers of observations. Researchers can either estimate the convergence rates from the large and fairly representative sample of countries with GDP data available from the 1960s or 1970s ("large N, small T"), or from the much more restricted sample of countries with data going back to the turn of the 20th century ("small N, large T"). Estimated convergence rates in the large-N-small-T sample will not pick up possible β-divergence in the first two thirds of the 20th century. Estimated convergence rates using a longer small-N-large-T sample are, on the other hand, unlikely to be representative. For example, Barro (2012) finds an upper bound of the rate of convergence of 2.4 percent since 1870 in the sample of 34 countries also shown here in Figure 7, panel C.[28] Inequality, as measured by dispersion in agricultural employment shares, was stable or declining (σ-convergence) among the 34 countries analyzed by Barro in the entire period. By contrast, inequality was rising until the 1970s in the larger sample of 116 countries in panel D, and they are more unequal today than in 1900. σ-divergence do not necessarily imply conditional β-divergence. Still, the rising inequality in the larger sample indicates that the rate of β-convergence estimated by Barro (2012) and others in small-N-large-T samples may be biased upward due to selection.

My agricultural employment share database provide a sample that is large in both the N and T dimensions. It is an interesting topic for further research to see if the results of the convergence literature, and the empirical growth literature more broadly, are robust to using

[26] *E.g.*, Galor (2005, 2011).

[27] See Durlauf *et al.* (2005) for an overview of the debate.

[28] It is an upper bound, as a finite time period and the presence of fixed effects in the regression causes an upward Nickell (1981) bias in the estimate.

the larger sample of agricultural employment shares rather than GDP data.

6.5 Predicting GDP revisions with agricultural employment

As shown above, well-known measurement errors in GDP in Africa, USSR and Eastern Europe are made clearly visible by comparing GDP data to agricultural employment shares. But agricultural employment shares are in general useful for detecting and correcting measurement errors in GDP data. To illustrate this, I use my database to predict GDP revisions following the publication of new benchmark estimates for PPPs. Predicting revisions is equivalent to predicting measurement errors if the revisions, on average, make GDP estimates more accurate. The excercise is related to Almås (2012), who use consumption data and Engel's Law to correct PPP estimates.[29]

The benchmark year for PPPs is changed when the results of a new ICP round is published. Updates happen infrequently, and often have huge impacts on relative GDP levels. Chinese real GDP was, for instance, reduced by 39 percent in 2008 following the publication of the results from the 2005 ICP. China's place in the world economy made popular media pay much attention to this change, but the size of the revision was not unique to the Middle Kingdom. As shown in Table 7, 24 countries had their estimates of real GDP per capita revised by more than China. The benchmark PPPs were revised once more when the results of the 2011 ICP were published in 2014, and the revisions were of the same magnitude as in the 2005 round.

To predict the GDP revisions, I use a two step procedure. In the first step, I estimate the following regression (corresponding to the regression lines in Figure 1 and Figure 4):

$$\log\left(\widetilde{y}_i^{old}\right) = \alpha_0 + \alpha_1 \widetilde{AES}_i + \varepsilon_i^{old}, \tag{6}$$

where $\widetilde{y}_i^{old}$ is measured GDP per capita before the revision, $\widetilde{AES}_i$ is the measured agricultural employment share, and ε_i is an error term. The latter can be decomposed into three parts:

$$\varepsilon_i^{old} = \varepsilon_i^{y,old} - \alpha_1 \varepsilon_i^{AES} + \varepsilon_i^{model}. \tag{7}$$

[29] Hamilton (2001) and Costa (2001) similarly use Engel's Law to correct consumer price indecies in the United States, with implications for estimates of real GDP growth.

Table 7: Revisions to PPP adjusted GDP after the 2005 ICP round

Country	Revision (%)	Country	Revision (%)
Congo	188	Ghana	-51
Yemen	137	Angola	51
Gabon	94	Ecuador	50
Lebanon	84	Comoros	-47
Zimbabwe	-74	Cambodia	-47
Nigeria	73	Venezuela	47
Kuwait	71	Ethiopia	-46
Congo, Dem. Rep.	-63	Central African Rep.	-45
Gambia	-62	Tanzania	44
Guinea	-60	Philippines	-43
Lesotho	-58	Namibia	-40
Cabo Verde	-51	Togo	-40

Source: The World Bank (2008), Appendix G

The first term on the right hand side, ε_i^y, is the measurement error in GDP per capita defined such that the true unobserved income level is given by $\log(y_i) = \log\left(\widetilde{y}_i^{old}\right) - \varepsilon_i^{y,old}$. The estimated residuals are thus correlated with the measurement error in the unrevised GDP numbers, and can be used to correct the GDP estimates by following the approach of Henderson *et al.* (2012), who use a weighted average of observed GDP and night lights measured from space as a measure of true GDP. The correlation is also useful to predict revisions to GDP. A revision is given by:

$$\begin{aligned} \Delta\varepsilon_i^y &= \log\left(\widetilde{y}_i^{new}\right) - \log\left(\widetilde{y}_i^{old}\right) \\ &= \varepsilon_i^{y,old} - \varepsilon_i^{y,new} \\ &= \varepsilon_i^{old} - \alpha_1\varepsilon_i^{AES} + \varepsilon_i^{model} - \varepsilon_i^{y,new} \end{aligned} \tag{8}$$

The terms $\varepsilon_i^{y,new}$, $\alpha_1\varepsilon_i^{AES}$ and ε_i^{model} are unobserved, but ε_i^{old} can be obtained from estimating Equation (6). If the revisions improve the income estimates, meaning that $cov\left(\Delta\varepsilon_i^y, \varepsilon_i^{y,old}\right) < 0$, then the parameter β_1 should be positive in a second step, where the revisions are regressed on the residuals from Equation (6):

$$\Delta\varepsilon_i^y = \beta_0 + \beta_1\varepsilon_i^{old} + u_i \tag{9}$$

Table 8: Predicting PPP revisions

Panel A: Results of regression (6)

	2005	**2011**
$\hat{\alpha}_1$ (estimated coefficient on AES_i)	-3.99	-4.43
Standard error	0.21	0.21
R^2	0.75	0.76
Observations	130	141

Panel B: Results of regression (9)

	2005	**2011**
$\hat{\beta}_1$ (estimated coefficient on ε_i^{old})	0.14	0.08
Standard error	0.05	0.02
R^2	0.06	0.07
Observations	130	141

Notes: The unrevised 2011 GDP estimates are calculated by the author using the constant PPP approach.
Sources: The World Bank (2008, 2014) and the United Nations National Accounts Main Aggregates Database.

The results of the first step are shown in Table 8, Panel A, for both the 2005 and the 2011 ICP rounds. Results from the second step, *i.e.*, the regression in Equation (9), are reported in Panel B. The estimates of β_1 are significant with $p < 0.01$ in both years, confirming that agricultural employment data are useful to predict revisions to GDP, and, by implication, useful for detecting measurement errors in the GDP data.

The R^2 is not particularly high in any of the two regressions in Panel B of Table 8 for three reasons: Country specific idiosyncrasies affects the relationship between the true income level and agricultural employment (*e.g.*, high land-to-labor ratios), measurement errors introduce noise in the agricultural employment data, and the GDP revisions did not remove all of the noise in the GDP data. The latter is especially important due to the many sources of measurement errors in GDP discussed in Section 2. It is also underscored by the need for consecutive large revisions to the PPPs.

The large revisions to the PPPs, and the possibility of predicting them using agricultural employment shares, emphasize that agricultural employment is a useful proxy for income. Moreover, both the PPP data, and the other data underlying estimates of real GDP, are likely to be less accurate further back in time than in the periods analyzed here. The usefulness of agricultural employment as an alternative to GDP data is thus likely to increase further back in time.

7 Concluding remarks and avenues for further research

I have collected and estimated agricultural employment shares for 169 countries in the period 1900-2010. Agricultural employment is closely related to national income, and reliable data are available for more countries and for longer periods than GDP estimates. The resulting database, available online, is useful for researchers studying economic growth, comparative development, economic history, or other related fields.

An obvious application of the database is to test the many theories directly concerned with agricultural employment, such as models of structural change, theories of how industrialization spread around the globe, and dual economy models. Other potential applications have been noted in this paper. Agricultural employment shares are, for instance, useful to detect and correct measurement errors in GDP. Perhaps more importantly, the availability of long time series for employment makes it possible to study long run growth and convergence in more representative samples of countries than the ones usually analyzed in the literature.

The larger sample of countries is likely to matter for the conclusions drawn. Inequality, measured by the dispersion of agricultural employment shares, was stable in the first three quarters of the 20th century among the countries with long time series of GDP data available in Maddison (2010) and in the Barro-Ursua data set. But among the countries in my larger sample, inequality rose by 50 percent during that period, corresponding to σ-divergence. This finding suggests that existing estimates of β-convergence rates may be overestimated as well. Estimating rates of β-convergence based on agricultural employment is an interesting topic for further research. And more generally, it will be interesting to see if the results of the empirical growth literature are robust to replacing GDP per capita with agricultural employment shares as the variable of interest.

Agricultural employment are also linked to many other important outcomes. The transition out of agriculture may, for instance, reduce fertility as it is harder to raise children when working outside of the home. It may also change the social standing of women, as nonagricultural work often is less physically demanding. Trade policies may likewise be affected when the composition of output changes. These are just a few examples. Changed sectoral employment patterns are likely to correlate with many other demographic, economic, social, and institutional variables.

It will also be interesting to study how agricultural employment is affected by global macro trends, such as the introduction of new technologies, lower transportation costs, and climate change. Understanding how climate change have interacted with agriculture around the world historically is particularly important, as it will give an indication of the economic consequences of further emissions of greenhouse gases.

Data collection projects, as the one presented here, are never entirely completed. It is my intention to update the database if, or when, more data come to light, and it is my hope that users of the database will contribute to this task.

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Data Appendix

This appendix gives an overview of the database and its underlying sources. More details can be found in the additional data in Wingender (2014b).

All independent countries with more than 250,000 inhabitants in 2010 are listed in the tables on the next pages. The second column of the tables contains the first year with available data. The third column contains the first year where the data point is based on employment data rather than estimated from urbanization rates. The data sources used are listed in the final column.

The following abbreviations are used in the final column for sources of employment data:

- ILO: International Labor Organization
- GGDC: Groningen Growth and Development Centre
- OECD: Organization for Economic Cooperation and Development
- IHS: International Historical Statistics from Mitchell (1993, 1998a,b).
- EF: Easterly and Fischer (1995)
- OLA: Oxford Latin America Economic History Database
- LoN: Statistical Yearbook of the League of Nations
- IPUMS: Calculations based on intregrated public use micro data from Sobek *et al.* (2013)
- NAPP: Calculation based on micro data from Minnesota Population Center (2008)
- My: Myers and Campbell (1954)
- NSO: Data collected from national statistics offices
- Good: Census data from the Habsburg empire kindly provided by David Good.

The following abbreviations are used in the final column for sources used to calculate urbanization rates:

- UN: United Nations
- IHS: as above
- Eg: Eggimann (1999)
- Ma: Manning (2010)
- Le: Lewis *et al.* (1976)
- Ka: Karpat (1985)
- Mc: McEvedy *et al.* (1978)

The remaining data sources are not abbreviated.

Country	**First obs.**	**First AES obs.**	**Sources**
Afghanistan	1920	1979	IHS, UN, Eg
Albania	1930	2002	ILO, NSO, UN, IHS
Algeria	1900	1948	ILO, IHS, UN, Eg
Angola	1900	1960	NSO, IHS, Eg, Ma
Argentina	1900	1902	GGDC, OLA, Eg, IHS
Armenia	1900	1970	ILO, EF, Le
Australia	1901	1901	IHS, ILO, OECD, GGDC
Austria	1900	1900	IHS, ILO, OECD, Good
Azerbaijan	1900	1970	ILO, EF, Le
Bahamas	1950	1973	ILO, UN, IHS, Eg
Bahrain	1950	1979	ILO, UN
Bangladesh	1900	1951	ILO, IHS, Eg, Mc
Barbados	1946	1946	ILO, IHS
Belarus	1900	1970	ILO, EF, Le
Belgium	1900	1900	OECD, GGDC, IHS
Belize	1950	1993	ILO, UN
Benin	1900	2003	ILO, UN, Eg, Ma
Bhutan	1900	2003	ILO, UN
Bolivia, Plurinational State of	1900	1950	GGDC, ILO, Eg, IHS
Bosnia and Herzegovina	1900	1900	ILO, IHS, My, Almanach de Gotha (1910)
Botswana	1950	1964	GGDC, UN
Brazil	1900	1900	GGDC, IHS, OLA, IPUMS
Brunei Darussalam	1950	1991	ILO, NSO, UN
Bulgaria	1900	1910	ILO, IHS, LoN, Lampe (1975)
Burkina Faso	1900	1985	ILO, IPUMS, UN, Eg, Ma
Burundi	1900	1979	ILO, IHS, UN, Eg, Ma
Cabo Verde	1950	2000	NSO, UN
Cambodia	1920	1962	ILO, IHS, UN, Eg,
Cameroon	1900	1976	ILO, IHS, UN, Eg, Ma
Canada	1900	1900	ILO, IHS, NAPP
Central African Republic	1900	1975	IHS, UN, Eg, Ma
Chad	1900	1993	ILO, NSO, UN, Eg, Ma
Chile	1900	1907	ILO, OLA, GGDC, Eg, IHS
China	1900	1980	ILO, IHS, Eg
Colombia	1900	1938	GGDC, ILO, OLA, Eg, IHS
Comoros	n.a.	n.a.	
Congo	1900	2005	ILO, UN, Eg, Ma
Congo, the Democratic Republic of the	1900	1952	IHS, UN, Eg, Ma
Costa Rica	1900	1950	GGDC, ILO, Eg, IHS
Côte d'Ivoire	1900	1964	NSO, IHS, UN, Eg, Ma
Croatia	1900	1900	ILO, IHS, My, Good
Cuba	1900	1919	OLA, ILO, IHS, Eg,

Country	**First obs.**	**First AES obs.**	**Sources**
Cyprus	1946	1946	KLEM, ILO, IHS
Czech Republic	1900	1900	OECD, GGDC, IHS, Good
Denmark	1900	1900	OECD, GGDC, IHS
Djibouti	n.a.	n.a.	
Dominican Republic	1900	1920	OLA, ILO, IHS, Eg
Ecuador	1900	1950	OLA, ILO, IHS, Eg
Egypt	1900	1907	ILO, IHS, Eg
El Salvador	1920	1950	OLA, ILO, IHS, Eg
Equatorial Guinea	1950	1983	ILO, UN
Eritrea	n.a.	n.a.	
Estonia	1900	1922	OECD, GGDC, ILO, EF, Lon, Le
Ethiopia	1900	1971	GGDC, IHS, UN, Eg, Ma
Fiji	1950	1956	IPUMS, IHS, UN
Finland	1900	1900	OECD, GGDC, IHS
France	1900	1900	OECD, GGDC, IHS
Gabon	1950	1963	ILO, IHS, Deldycke *et al.* (1968), UN
Gambia, The	1900	1993	ILO, UN, Eg, Ma
Georgia	1900	1970	ILO, EF, Le
Germany	1900	1900	OECD, IHS
Ghana	1900	1960	GGDC, IHS, UN, Eg, Ma
Greece	1920	1920	OECD, GGDC, IHS
Guatemala	1900	1950	OLA, ILO, IHS, Eg
Guinea	1950	1983	ILO, IPUMS, UN
Guinea-Bissau	n.a.	n.a.	
Guyana	1900	1946	ILO, IHS, Eg
Haiti	1900	1950	OLA, ILO, IPUMS, IHS, Eg
Honduras	1900	1950	OLA, ILO, IHS, Eg
Hong Kong	1920	1974	ILO; GGDC, UN, Eg, IHS
Hungary	1900	1900	OECD, ILO, IHS, Good
Iceland	1900	1900	ILO, LoN, NAPP
India	1900	1901	GGDC, ILO, Eg, Mc
Indonesia	1900	1905	GGDC, ILO, IHS, Eg, Mc
Iran, Islamic Republic of	1900	1956	ILO, IHS, UN, Eg
Iraq	1900	1957	ILO, IHS, UN, Eg
Ireland	1900	1900	OECD, GGDC, IHS, LoN
Israel	1948	1948	OECD, ILO, IHS
Italy	1900	1900	OECD, GGDC, IHS
Jamaica	1920	1943	ILO, IHS, Eg
Japan	1900	1872	OECD, GGDC, IHS
Jordan	1950	1961	ILO, IHS, UN
Kazakhstan	1900	1970	ILO, EF, Le

Country	First obs.	First AES obs.	Sources
Kenya	1900	1969	GGDC, UN, Eg, Ma
Korea, Democratic People's Republic of	n.a.	n.a.	
Korea, Republic of	1955	1955	OECD, GGDC, IHS, Chung (2006)
Kosovo	1921	1921	NSO, IHS, My
Kuwait	1950	1983	ILO, UN
Kyrgyzstan	1897	1970	ILO, EF, Le
Lao People's Dem. Rep.	1950	1995	NSO, UN
Latvia	1900	1925	GGDC, ILO, EF, LoN, Le
Lebanon	1910	1970	NSO, IHS, UN, Eg, Ka
Lesotho	1900	1999	NSO, ILO, UN, Eg, Ma
Liberia	1900	1962	ILO, IHS, UN, Eg, Ma
Libya	1900	1964	ILO, IHS, UN, Eg, Ma
Lithuania	1900	1923	GGDC, ILO, EF, LoN, Le
Luxembourg	1907	1907	OECD, GGDC, Deldycke *et al.* (1968)
Macedonia, the FYD of	1921	1921	ILO, IHS, My
Madagascar	1900	1993	NSO, ILO, UN, Eg, Ma
Malawi	1900	1966	GGDC, UN, Eg, Ma
Malaysia	1920	1947	GGDC, ILO, IHS, Eg, McGee (1964)
Maldives	1950	1990	NSO, ILO, UN, Eg, Ma
Mali	1900	1976	ILO, IHS, UN, Eg, Ma
Malta	1948	1948	KLEMS, ILO, Deldycke *et al.* (1968)
Martinique	1950	1961	ILO, IHS, UN
Mauritania	n.a.	n.a.	
Mauritius	1900	1952	GGDC, IHS, UN, Eg, Ma
Mexico	1900	1910	OECD, GGDC, OLA, Eg, IHS
Moldova, Rep. of	1900	1970	ILO, EF, Le
Mongolia	1920	1993	ILO, UN, Eg, IHS
Montenegro	1921	1921	ILO, IHS, My
Morocco	1900	1952	ILO, IHS, UN, Eg, Ma
Mozambique	1900	1950	ILO, IHS, Eg, Ma
Myanmar	1920	1978	ILO, Eg, IHS
Namibia	1950	1960	ILO, IHS, UN
Nepal	1900	1961	NSO, ILO, IHS, UN, Eg
Netherlands	1900	1900	OECD, GGDC, IHS, ILO, Smits *et al.* (1999)
New Zealand	1900	1900	OECD, ILO, IHS
Nicaragua	1900	1940	OLA, ILO, IHS, Eg
Niger	1900	1960	ILO, IHS, UN, Eg, Ma
Nigeria	1900	1960	Adeyinka *et al.* (2013), GGDC, UN, Eg, Ma
Norway	1900	1900	OECD, IHS, NAPP
Oman	1950	1993	ILO, UN
Pakistan	1900	1951	ILO, IHS, UN, Eg, Mc
Panama	1900	1940	OLA, ILO, Eg, IHS

Country	First obs.	First AES obs.	Sources
Papua New Guinea	1900	2000	ILO, UN, Eg, IHS
Paraguay	1900	1950	OLA, ILO, IHS, Eg
Peru	1900	1940	GGDC, ILO, OLA, IPUMS, IHS, Eg
Philippines	1900	1939	GGDC, ILO, IHS, Eg
Poland	1900	1900	OECD, GGDC, ILO, IHS, Deldycke *et al.* (1968)
Portugal	1900	1900	OECD, GGDC, IHS
Qatar	1950	1997	ILO, UN
Romania	1913	1913	ILO, IHS, UN, Good
Russian Federation	1900	1970	ILO, EF, Le
Rwanda	1900	1978	ILO, IHS, UN, Eg, Ma
Saudi Arabia	1950	1992	ILO, UN
Senegal	1900	1971	GGDC, UN, Eg, Ma
Serbia	1900	1900	ILO, IHS, My, Good
Sierra Leone	1900	1963	ILO, IHS, UN, Eg, Ma
Singapore	1920	1947	GGDC, IHS, Eg
Slovakia	1900	1900	OECD, GGDC, ILO, IHS, Good
Slovenia	1900	1900	OECD, GGDC, ILO, My, Good
Solomon Islands	1950	2009	NSO, UN
Somalia	n.a.	n.a.	
South Africa	1911	1911	GGDC, IHS
South Sudan	1950	2008	IPUMS, UN
Spain	1900	1900	OECD, GGDC; ILO, IHS
Sri Lanka	1900	1946	ILO, IHS, Eg
Sudan	1900	1956	IHS, UN, Eg, Ma
Suriname	1950	1973	ILO, UN
Swaziland	n.a.	n.a.	
Sweden	1900	1900	Schön and Krantz (2012)
Switzerland	1900	1900	OECD, ILO, IHS
Syrian Arab Republic	1900	1960	ILO, IHS, UN, Eg, Ka
Taiwan, Province of China	1905	1905	GGDC, ILO, IHS
Tajikistan	1900	1970	ILO, EF, Le
Tanzania, United Republic of	1900	1960	GGDC, UN, Eg, Ma
Thailand	1900	1937	GGDC, ILO, IHS, Eg
Timor-Leste	1950	2001	NSO, ILO, UN
Togo	1900	1981	ILO, IHS, UN, Eg, Ma
Trinidad and Tobago	1946	1946	ILO, IHS
Tunisia	1900	1956	ILO, IHS, UN, Eg, Ma
Turkey	1900	1927	ILO, IHS, Eg, Ka
Turkmenistan	1900	1970	EF, UN, Le
Uganda	1900	1991	ILO, IPUMS, UN, Eg, Ma
Ukraine	1900	1970	ILO, EF, Le
United Arab Emirates	1950	1995	ILO, UN

Country	First obs.	First AES obs.	Sources
United Kingdom	1900	1900	OECD, KLEMS, ILO, IHS
United States	1900	1900	OECD, KLEMS, ILO, IHS
Uruguay	1900	1950	OLA, IPUMS, IHS, Eg
Uzbekistan	1900	1970	ILO, EF, Le
Venezuela, Bolivarian Republic of	1900	1925	GGDC, OLA, ILO, IHS, Eg
Viet Nam	1920	1992	NSO, ILO, UN, Eg, IHS
Yemen	1950	1991	ILO, UN
Zambia	1900	1969	GGDC, UN, Eg, Ma
Zimbabwe	1900	1999	NSO, ILO, UN, Eg, Ma

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Skill Complementarity and the Dual Economy

Asger Moll Wingender

Abstract

I estimate that the elasticity of substitution between skilled and unskilled workers is higher in agriculture than in nonagriculture, and argue that this difference is an important explanation for the relatively unproductive agrarian sectors observed in developing countries. To illustrate the argument, I simulate a simple two-sector model, and show that heterogeneous elasticicities of substitution affect the sectoral allocation of human capital, and therefore relative productivity levels. Calibrated to match data from the United States, the model predicts sizable agricultural productivity gaps in countries where the share of highly educated workers in the labor force is low.

1 Introduction

Many developing countries are dual economies. They have large agricultural sectors with productivity levels that trail productivity in the nonagricultural sector by an order of magnitude. Rich countries, on the other hand, have small and relatively productive agricultural sectors. Closing the agricultural productivity gap in developing countries will substantially diminish the income gap between rich and poor countries. This empirical fact was noted by Kuznets (1971), and is well documented in a series of recent papers by Caselli (2005), Temple (2005), Chanda and Dalgaard (2008), Vollrath (2009b), Temple and Wößmann (2006), Restuccia *et al.* (2008), McMillan and Rodrik (2011), and Gollin *et al.* (2014).[1]

[1] Agriculture is, by empirical necessity, often used as a stand in sector for a backward traditional sector. Nonagriculture is similarly associated with the modern sectors in the economy. The terminology differ from

The dual economy is reflected in the sectoral allocation of human capital. Agricultural workers tend to have lower educational attainment than their compatriots working in other sectors, and the difference is larger in countries where the agricultural productivity gap is large.[2]

The standard way to model such an allocation of human capital is to assume that workers with high education levels, or strong cognitive abilities, have a comparative productivity advantage in nonagriculture.[3] The central argument of this paper is that it is easier to substitute skilled and unskilled workers for each other in agriculture than in nonagriculture, and that this difference provides an equally simple and empirically relevant mechanism behind the observed allocation of human capital. Moreover, as we shall see below, it provides more plausible predictions about the return to education. The two mechanisms are complementary, however. Combined, they generate larger agricultural productivity gaps in countries with few skilled workers than they do individually.

The idea that skilled and unskilled workers are easier to substitute for each other in agriculture is based both on empirical observation and economic intuition. In a sample of 62 countries, I find that the elasticity of substitution between skilled and unskilled workers in agriculture is 1.5-2 times larger than in nonagriculture.

Intuitively, many different types of workers interact in the production processes that lead to the nonagricultural goods and services we consume. Manufacturing does, for example, rely on skilled workers for installing and maintaining machinery, accounting, marketing. Such workers are employed along with a relatively unskilled labor force on the factory floor.

The same pattern do not apply in agriculture. Both history, and the reality of developing countries today, confirm that agricultural production often take place on small independent plots of land tilled by a few members of a single household. Farms are larger in terms of land in developed countries, but not in terms of the number of people employed.[4] There is

paper to paper cited here and below, but I use the agriculture/nonagriculture distinction no matter the original wording in the cited papers.

[2] Gollin *et al.* (2014). See also Section 2 below.

[3] *E.g.*, Caselli and Coleman (2001), Lucas (2004) and Lagakos and Waugh (2013). The extreme version of this assumption is that human capital do not contribute to productivity in agriculture.

[4] The average number of workers per farm is 1.5 in the US, 2.0 in the OECD, and 2.4 i countries not in

thus less scope for interaction between workers of different types in agriculture. Moreover, farmers in the developed world are usually well educated, and have an extensive knowledge of the newest farming technologies, whereas their counterparts in poorer countries often lack formal education. Yet, both are able to grow the same crops, although with different efficiency. It is, by contrast, inconceivable that an electronics manufacturer would be able to produce a single device without employing any skilled workers. The same logic applies to many other nonagricultural industries, including services, and points to a greater degree of complementary between workers in nonagriculture than in agriculture.[5]

Skill complementarities make it harder to substitute one type of labor for another, and the marginal products of skilled and unskilled workers thereby become sensitive to the composition of the labor force. Firms (and farms) will bid up wages for skilled workers when they are in short supply, and more so when it is hard to replace them with unskilled workers. Equivalently, at a given wage rate, the demand for skilled workers will be higher.

Labor mobility eliminates any sectoral differences in wages. Given an equilibrium wage rate, the demand for skilled workers in nonagriculture will, due to the higher skill complementarity in the sector, be higher than in agriculture in an economy with few skilled workers. A larger *fraction* of the skilled labor force will consequently be employed in nonagriculture. Nonetheless, the demand for unskilled labor will be relatively low in nonagriculture, since the skill complementarity reduces the number of unskilled workers that are demanded alongside the skilled workers at a given equilibrium wage rate. The ratio of skilled-to-unskilled workers will consequently be higher in nonagriculture than in agriculture when skilled workers are few.

The education gap, and hence the productivity gap, narrows when the share of skilled workers in the population increases, as an increased supply have a disproportional effect on the marginal products of labor in nonagriculture, where the skill complementarity is higher. Sectoral differences in skill complementarities do in that sense help to explain both the dual economy and how an initially backward agricultural sector modernizes when a country accu-

the OECD. Sources: FAO World Agriculture Census 2000, United States Census Bureau (Statistics of U.S. Businesses 2008), and Bureau of Labor Statistics.

[5] The argument above is taken to the extreme for illustrative purposes. Taken at face value, it favors perfect substitution between workers in agriculture.

mulates human capital.

I build the mechanism sketched above into a simple two-sector model, and calibrate its parameters to match data from the United States. A reasonable test of the model is to see how well its predictions fare out of sample, *i.e.*, across developing countries. In the model, countries only differ with respect to the aggregate human capital stock. Depending on how skilled workers are defined, the model generates relative agricultural productivity levels in the 0.20-0.6 range in a hypothetical country where less than 10 percent of the labor force is skilled. The lower end of the interval is in line with the agricultural productivity levels observed in such countries, indicating that the explanatory power of the model is high.

The agricultural productivity gap is in the model caused by both a comparative advantage of skilled workers in nonagriculture, and by heterogeneous elasticities of substitution. Alone, heterogenous elasticities lead to relative agricultural productivity levels in the 0.45-0.65 range. Both channels are thus individually important for the dual economy phenomenon, and the impact on relative productivity levels is larger when they are combined.

The model also does well in other dimensions, too. It predicts that agricultural employment is high in countries with few skilled workers. Moreover, the model generates a substantially lower skill premium in developing countries than a model without heterogenous skill elasticities does, and it is therefore more in line with the empirical estimates of mincerian returns to education found in the literature.[6]

The model does not have any frictions. By contrast, most theoretical dual economy models have inefficient factor markets, transportation costs, externalities, or other distortions at their cores.[7] Other models rely on a subsistence food requirement that increases the employment share in agriculture in poor (closed) economies. Lagakos and Waugh (2013) argue, for instance, that many individuals therefore are forced to work in agriculture, although they are relatively unproductive when performing agricultural tasks. Only the individuals with the highest productivity levels will work in nonagriculture, and the authors argue that this se-

[6]See Banerjee and Duflo (2005), and the discussions in Sections 2 and 6.

[7]Examples are Restuccia (2004), Gollin *et al.* (2004), Graham and Temple (2006), Landon-Lane and Robertson (2007), Restuccia *et al.* (2008), Satchi and Temple (2009), Vollrath (2009a), Rodrik (2009), Adamopoulos (2011) and Gollin and Rogerson (2014).

lection mechanism can account for the dual economy. While both frictions and subsistence needs arguably are present in developing countries, the results of this paper indicate that their impact on relative sectoral productivity levels may be smaller than what is often assumed.

The dual economy literature is related to papers dealing with structural transformation in multi-sector models.[8] Close to this paper is Caselli and Coleman (2001) and Lucas (2004), who provide models in which human capital is the main driver of the transition out of agriculture. It is in both models assumed that the acquisition of human capital only increases labor productivity in the nonagrarian sector. Skilled workers will consequently never choose to work in the agrarian sector, and the economies are dual in terms of education levels by assumption, no matter aggregate income levels or human capital stocks. They are in that sense unable to explain how agriculture catches up to other sectors along this dimension. Adding the mechanism for endogenous allocation of human capital proposed in this paper will allow such models to make more realistic predictions about the transition out of agriculture, and thus to expand their explanatory power.

This paper is also closely related to Caselli and Coleman (2006), who estimate the relative productivity advantage of skilled workers in a cross section of countries. They find that richer countries use skilled workers more efficiently than lower-income countries, and interpret their results as a sign of a skill bias in technology adoption. However, as Caselli and Coleman (2006) acknowledge, their results are observationally equivalent with a model in which technology is fixed, and the elasticity of substitution is allowed to vary with development.[9] The latter is the case in my model. The higher elasticity in agriculture, combined with an agricultural employment share that depends on aggregate human capital, imply that the elasticity of substitution in the *aggregate economy* varies with development. The model of this paper can thus serve as a two-sector foundation to the one-sector result in Caselli and Coleman (2006).

Alvarez-Cuadrado and Van Long (2012) study a model in which the capital-labor complementarity varies across sectors, and show that this mechanism can be a driver of structural change. Their hypothesis finds empirical support in Herrendorf *et al.* (2013), who estimate

[8] *E.g.*, Hansen and Prescott (2002), Gollin *et al.* (2007), Strulik and Weisdorf (2008), Lucas (2009) and Herrendorf *et al.* (2014).

[9] See Diamond *et al.* (1978) for general statement of this theorem.

that the elasticity of substitution between capital and labor in agriculture is 1.58 in the United States, twice as high as in manufacturing and services. There is a link between these findings, and the results presented here. Capital has often been shown to be more complementary to skilled workers than to unskilled workers, and the estimated elasticity of substitution between capital and land in Herrendorf *et al.* (2013) is therefore likely to reflect that relatively few skilled workers are employed in agriculture compared to the other sectors.[10] Why we observe such an allocation of skills is something that the model in this paper can help to explain.

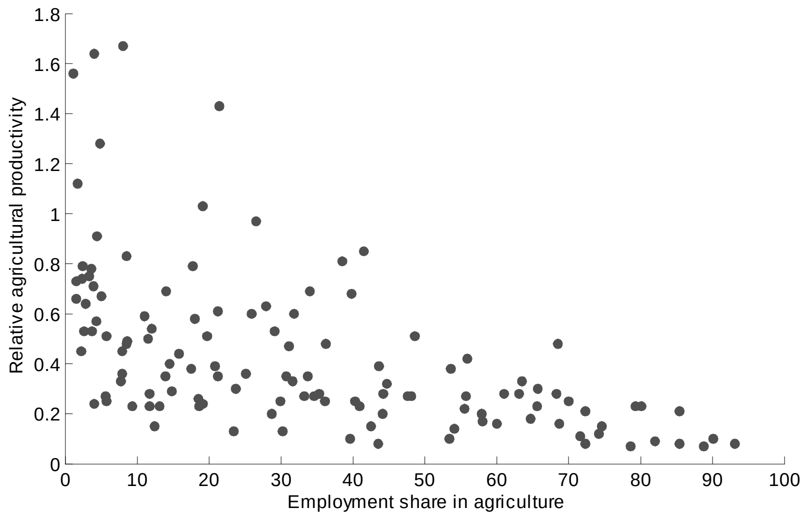
The paper is organized as follows. Some empirical facts about human capital, skill complementarity, and productivity are reviewed in Section 2. The model is summarized in Section 3. Based on an equation from the model, the relative elasticity of substitution between skilled and unskilled workers in agriculture is estimated in Section 4. The model cannot be solved analytically, and the predictions of the model are therefore illustrated by simulations based on parameters calibrated to match data from the United States. The calibration and simulations of the relative agricultural productivity level are shown in Sections 5. Predictions about the agricultural employment share and the return to education are discussed in Section 6. Section 7 concludes.

2 Human capital and productivity

Some of the empirical findings that motivate this paper are briefly reviewed in this section. Figure 1 shows agricultural employment shares and ratios of agricultural labor productivity to nonagricultural labor productivity in a sample of 123 countries compiled by Gollin *et al.* (2014). The dual economies are located in the lower right corner, where the employment share in agriculture is high and the relative productivity level low. The coefficient of correlation between the two variables is -0.55. Relative productivity in agriculture is above 0.7 in rich countries such as Australia, Sweden, and the United States, whereas many developing nations with high employment shares in agriculture have a relative agricultural productivity level of just 0.1. Closing the sectoral productivity gap (alternatively, lowering the employment share in

[10] Numerous studies of capital-skill complementarity have been made since it was first suggested by Griliches (1969). Notable examples are Fallon and Layard (1975), Goldin and Katz (1998), and Krusell *et al.* (2000).

Figure 1: The dual economy



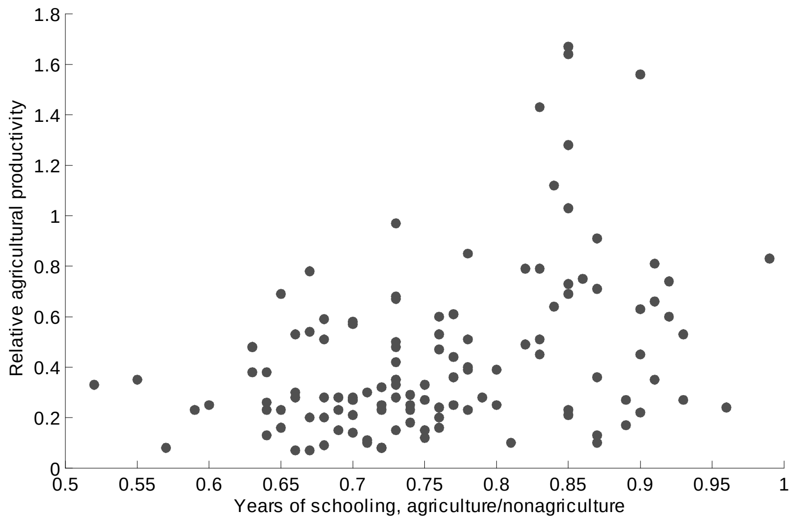
agriculture to rich-country levels) would therefore have a huge impact on the aggregate income level of developing countries with dual economies.

The most dual economies in terms of the agricultural productivity gap are also the economies with the least educated labor force. It is hardly a surprise, since it is well known that aggregate human capital and aggregate income is positively correlated. A more interesting question is whether there is a quantitatively important link between the sectoral allocation of skilled workers and relative sectoral productivity levels. The answer seems to be yes. As shown in Figure 2, there is a positive relationship between relative agricultural productivity and the average years of schooling completed among agricultural workers relative to workers in other sectors. The coefficient of correlation is 0.40.

Based on the data in Figure 2 and mincerian returns to education, Gollin *et al.* (2014) estimate that roughly one third of the agricultural productivity gap can be accounted for by sectoral differences in human capital.

Empirical estimates of mincerian returns, including those used in Gollin *et al.* (2014), show little variation across countries. In particular, they are only weakly related to the supply of human capital in a country's labor force, and are therefore consistent with a productive technology in which workers with different skill levels are close to being perfect substitutes (assuming

Figure 2: The agricultural education gap



that productive technology and the quality of education is the same across countries).

Workers with different skill levels are, however, in many models of economic growth treated as distinct inputs that are not easily substituted for each other.[11] Taken to its extreme, no matter how many high school drop-outs you put together, they cannot perform the work of a heart surgeon. This view is supported by the empirical estimates of the elasticity of substitution between workers with different education levels found in Johnson (1970) Fallon and Layard (1975), Katz and Murphy (1992), Angrist (1995), Murphy *et al.* (1998), Krusell *et al.* (2000), Ciccone and Peri (2005) and Ottaviano and Peri (2012). Most of the studies report an elasticity close to 1.5. The highest estimates are found in Angrist (1995) and Ottaviano and Peri (2012), who put the elasticity at 2. Such estimates imply a great deal of complementarity between workers with different skill levels, and complementarities makes the return to education highly sensitive to the supply of human capital. Exactly the opposite of what the empirical estimates of mincerian returns suggest.

Heterogenous elasticities of substitution across sectors go some way in explaining this apparent inconsistency. Most estimates of the elasticity of substitution are based on aggregate

[11] *E.g.*, Eicher and Garcıa-Penalosa (2001), Acemoglu (2002), and Vandenbussche *et al.* (2006), as well as many of the papers cited in the introduction.

data from the US, or other rich countries, with negligible agricultural employment shares.[12] The estimates of the aggregate elasticity will therefore correspond closely to the elasticity of substitution in the nonagrarian sector. Similarly, agriculture is the dominant sector in many developing countries. If the elasticity of substitution is higher in agriculture, it follows that the aggregate elasticity of substitution must be higher in developing countries than in the rich countries studied by the literature, simply because agriculture carries more weight. By implication, the return to education in developing countries will be lower than what an aggregate elasticity of 1.5 entails.

3 A Simple Model

Before a further discussion of sectoral differences in the elasticity of substitution between workers with different skill levels, it is useful to write down a model. Let there be two types of workers in the model: highly skilled, H, and unskilled, L. The supplies of the two labor types are fixed and exogenous. The aggregate labor supply is normalized to unity such that H and L are equal to the shares of skilled and unskilled workers in the total population. The economy consists of two sectors: agriculture and nonagriculture. Labor inputs and outputs in the two sectors are labelled with subscript a and n respectively.

The structure of the workforce implies the following supply constraints on the labor market:

$$H_a + H_n \leq H \ , \tag{1}$$

$$L_a + L_n \geq L \ , \tag{2}$$

$$H + L = 1 \ . \tag{3}$$

Aggregate production in the two sectors is given by:

$$Y_a = X^{\alpha} \left(\beta \left(A H_a \right)^{\sigma} + \left(1 - \beta \right) L_a^{\sigma} \right)^{\frac{1-\alpha}{\sigma}}$$

[12] The exception is Angrist (1995), who use a Palestinian labor force survey.

$$Y_n = P\left(\gamma\left(AH_n\right)^{\rho} + (1-\gamma)\, L_n^{\rho}\right)^{\frac{1}{\rho}}$$

Land, denoted X, is in fixed supply, and agricultural production is assumed to exhibit diminishing returns to labor. I abstract from capital in both sectors, and there is consequently constant returns to the labor input in manufacturing. [13]

The agricultural good is chosen as numeraire, and P is the relative price of manufactured goods assumed to be set exogenously on the world market. Alternatively, P can be interpreted as a sector specific TFP term. The open economy assumption is convenient, since I do not have to take a stand on consumer preferences. A closed economy version of the model where relative prices set by households optimizing standard utility functions, will lead to conclusions similar to the ones derived from the simpler structure assumed here.

Skilled workers have the ability to operate the newest technology in production, giving them a relative productivity level $A \geq 1$. The absolute productivity advantage A is assumed to be similar in both sectors. Any *comparative* advantage of skilled workers in one of the sectors will in the model be summarized by a higher share parameter for skilled workers. If nonagriculture, for instance, requires more skilled workers than agriculture, it will translate into $\gamma > \beta$.

The key parameters of interest are the elasticities of substitution between skilled and unskilled workers in the two sectors, given by $\varepsilon_a = \frac{1}{1-\sigma}$ and $\varepsilon_n = \frac{1}{1-\rho}$. If $\varepsilon_a = \varepsilon_n = 1$, the production functions collapse into Cobb-Douglas functions.

Perfect mobility in the labor market ensures that workers will earn the same wage in both sectors, and profit maximization equalize these wage rates with their marginal products. Let w_H and w_L denote the wage rates of skilled and unskilled workers respectively. The first order conditions from profit maximization yields:

$$\frac{\partial Y_a}{\partial H_a} = (1-\alpha)\, X^{\alpha}\left(\beta\left(AH_a\right)^{\sigma} + (1-\beta)\, L_a^{\sigma}\right)^{\frac{1-\alpha-\sigma}{\sigma}} \beta A^{\sigma} H_a^{\sigma-1} = w_H \tag{4}$$

[13] This abstraction does not matter for relative productivty levels if two requirements are met: 1) the elasticity of substitution between (human capital weighted) labor and capital is one, corresponding to the standard Cobb Douglas formulation, and 2) the (nonland) capital income share is the same in the two sectors. Valentinyi and Herrendorf (2008) document that the latter is indeed the case in the United States. The income shares of capital are, according to their estimates, 0.36 in agriculture and 0.33 in nonagriculture.

$$\frac{\partial Y_a}{\partial L_a} = (1-\alpha) X^{\alpha} \left(\beta (AH_a)^{\sigma} + (1-\beta) L_a^{\sigma}\right)^{\frac{1-\alpha-\sigma}{\sigma}} (1-\beta) L_a^{\sigma-1} = w_L \tag{5}$$

$$\frac{\partial Y_n}{\partial H_n} = P \left(\gamma (AH_n)^{\rho} + (1-\gamma) L_n^{\rho}\right)^{\frac{1-\rho}{\rho}} \gamma A^{\rho} H_n^{\rho-1} = w_H \tag{6}$$

$$\frac{\partial Y_n}{\partial L_n} = P \left(\gamma (AH_n)^{\rho} + (1-\gamma) L_n^{\rho}\right)^{\frac{1-\rho}{\rho}} (1-\gamma) L_n^{\rho-1} = w_L. \tag{7}$$

The allocation of skilled and unskilled workers follows from the labor market equilibrium conditions (4)-(7) along with the supply constraints (1)-(3). The allocation cannot be derived analytically, and numerical methods have to be used.

Labor market mobility implies that the skill premium is the same in agriculture and in nonagriculture as long as both types of labor are present in both sectors, *i.e.*, that:

$$\frac{w_H}{w_L} = \frac{\beta}{1-\beta} A^{\sigma} \left(\frac{H_a}{L_a}\right)^{\sigma-1} = \frac{\gamma}{1-\gamma} A^{\rho} \left(\frac{H_n}{L_n}\right)^{\rho-1}. \tag{8}$$

Both types of workers are essential to production when they are imperfect substitutes, as it is assumed here, and Equation (8) therefore holds by construction.[14] However, without further assumptions, the skill premium may fall below unity, a situation that is clearly unrealistic. Skilled workers can perform unskilled work, and will choose to do so if the wage for skilled work fall below the wage for unskilled work.[15] I therefore impose that $\frac{w_H}{w_L} \geq 1$. When this restriction binds, some skilled workers are present in the unskilled occupations, and the supply constraints $H_a + H_n \leq H$ and $L_a + L_n \geq L$ no longer bind. The supply constraints are therefore replaced by two constraints on the skill premia when solving for the equilibrium:

[14] If skilled and unskilled workers were assumed to be perfect substitutes, then the skill premia in the two sectors would be $\frac{\beta}{1-\beta}A$ and $\frac{\gamma}{1-\gamma}A$ respectively, and independent on the supply and allocation of skills. That will lead to an extreme allocation of human capital akin to the one in Lucas (2004) and Caselli and Coleman (2001), since the two types of workers will select into the sectors where they have a comparative advantage. Assuming that $\beta < \gamma$, it implies that skilled workers will only work in agriculture if no unskilled workers are present in nonagriculture (*i.e.*, when Equation (8) does not bind). While that may serve an illustrative purpose in a model, I consider such a scenario empirically implausible.

[15] I assume that when skilled workers lose their inherent productivity advantage A when they are employed in low skill jobs.

$$\frac{w_H}{w_L} = \frac{\beta}{1-\beta} A^{\sigma} \left(\frac{H_a}{L_a}\right)^{\sigma-1} = 1$$

and

$$\frac{w_H}{w_L} = \frac{\gamma}{1-\gamma} A^{\rho} \left(\frac{H_n}{L_n}\right)^{\rho-1} = 1.$$

The only movable part of the model is the share of skilled workers in the labor force, H. For given assumptions about the parameters $X, A, \beta, \gamma, P, \varepsilon_a$ and ε_n, the allocation of skilled workers, productivity levels and wages follow from H. The model is nonlinear and has to be solved numerically based on the assumed parameters.

4 Estimating the elasticity of substitution in agriculture

At the heart of the model is the assumption that workers with high skill levels are distinct from less skilled workers in the production process. Intuitively, skilled workers can handle advanced mental or physical tasks that require special training. The two elasticities of substitution, ε_a and ε_n, summarize this intuition.

As mentioned in Section 2, most estimates of the elasticity of substitution between skilled and unskilled workers are close to 1.5 in aggregate data. Plausible values for ε_n will have to be in this ballpark, since most of the empirical studies are based on data from the United States or other countries where employment in agriculture is negligible.

Less is known about ε_a. The the hypothesis of this paper is that $\varepsilon_n < \varepsilon_a$, and Equation (8) allows this hypothesis to be tested formally. The equation can be rewritten into an empirical counterpart for a country i:

$$\ln\left(\frac{H_{n,i}}{L_{n,i}}\right) = \lambda_0 + \lambda_1 \ln\left(\frac{H_{a,i}}{L_{a,i}}\right) + u_i \tag{9}$$

where u_i is a country specific error term, $\lambda_0 = \frac{1}{\rho-1}\ln\left(\frac{\beta}{1-\beta}\frac{1-\gamma}{\gamma}A^{\sigma-\rho}\right)$ and $\lambda_1 = \frac{\sigma-1}{\rho-1} = \frac{\varepsilon_n}{\varepsilon_a}$. An estimated λ_1 less than unity indicates that skilled and unskilled workers are indeed easier to substitute in agriculture than in nonagriculture.

Following the literature, I use education levels to distinguish between skilled and unskilled workers. It is, however, not clear at what level of educational attainment the cut-off should be put. Using aggregate data from the United States, Ottaviano and Peri (2012) estimate the elasticity of substitution between workers with college education and workers with less than college to be 2. The estimated elasticity of substitution between high school graduates and individuals with less than high school is, on the other hand, larger than 25. By implication, college education seems to distinguish skilled workers from unskilled workers in the United States.

The United States is one of the leading countries in the world when it comes to education. An American high school graduate with no college education is likely to work as a waiter, or in a similar occupation with a low skill requirement. By contrast, a high school diploma in a developing country, where skills are scarce, are likely to land a relatively skill intensive job. Moreover, the educational systems in many countries, notably in Europe, place emphasis on technical and vocational training. While such programs usually do not count as college (tertiary) education in international education statistics, they are likely to provide graduates with specialized skills that are not easily substituted for by workers with less education. It is thus not clear whether the results of Ottaviano and Peri (2012) are externally valid.

I consequently estimate equation (9) based on three definitions of skilled workers. The results are reported in Table 1. The analysis is based on national census data from a sample of 62 countries, representing all income levels, and all regions of the world.[16] The data set is provided in an appendix to this paper.

The estimated λ_1 is 0.66 when skilled workers are defined as having completed secondary education. The elasticity of substitution between skilled and unskilled workers is therefore 1.5 times larger in agriculture than in nonagriculture. The fit of the model is good, with an R^2 of 0.79. The estimated λ_1 is 0.51 when skilled workers are defined as having completed some tertiary education, meaning that ε_a must be twice as high as ε_n.

38 percent of the labor force in the average country in the sample has completed secondary education, whereas only 10 percent has completed some tertiary education. In the light of

[16] The data are downloaded from the IPUMS-International database provided by Sobek *et al.* (2010). See data appendix for further details.

Table 1: OLS regressions of Equation (9)

Definition of skilled workers	Estimated λ_1	Std.	R^2	Obs.	Mean share of skilled workers
Secondary edu.completed	0.66	0.04	0.79	62	0.38
Some tertiary edu.completed	0.51	0.03	0.65	62	0.10
Some tertiary edu.or technical edu.completed	0.52	0.04	0.74	62	0.19

Notes: based on national census data from 62 countries. See the data appendix to this paper for details.

the discussion of technical secondary education above, a third definition of skilled workers is made in Table 1: workers with either some tertiary education, or with completed technical secondary education. With this definition, the average country in the sample has 19 percent skilled workers in its labor force, of which 9 percentage points have a technical degree. The estimated λ_1 is in this case almost the same as when skilled workers is defined as having completed some tertiary education. One interpretation of this result is that individuals with technical secondary education should indeed be categorized as skilled workers, at least for the purpose of comparing elasticities of substitution in the two sectors. It is, however, not possible to do so in what follows, since the model is calibrated to fit data from the United States, where formal vocational training is a rarity.

By interpreting the estimates in Table 1 as relative elasticities, it is implicitly assumed that the productivity parameter A, and the share parameters for skilled workers, β and γ, are independent of both the level and the allocation of human capital. One could, alternatively, assume that A is a function of the share of skilled workers, as in Caselli and Coleman (2006). However, as proved by Diamond *et al.* (1978), it is not possible to estimate technology bias and variation in the elasticity of substitution in a one-sector model. The corresponding result in the two-sector model of this paper is that it is not possible to estimate cross country variation in A, β and/or γ without making ex ante assumptions about the elasticities. In fact, a model with varying A and $\varepsilon_a = \varepsilon_m$ can be observationally equivalent to a model with constant A and $\varepsilon_a \neq \varepsilon_m$, a point also made by Caselli and Coleman (2006). Whether the estimated λ_1 reflects a technology bias, or sectoral differences in the elasticity of substitution, is purely a matter of interpretation.

In contrast to Caselli and Coleman (2006), I interpret the results in Table 1 as a sign of heterogenous elasticities of substitution. I do so for the following reasons. First, there is no theoretical argument of why the elasticity of substitution should be identical across sectors. On the contrary, at argued in the introduction to this paper, it seems intuitive that skilled and unskilled workers are easier to substitute in agriculture than in nonagriculture. It is hard to imagine a big manufacturing firm operate without both engineers and manual workers. Crops, the other hand, are grown and harvested by unskilled manual labor alone in many developing countries, whereas independent farmers in the rich world often are highly skilled.

Second, Herrendorf *et al.* (2013) estimate that another elasticity of substitution, namely the one between capital and labor, is twice as high in agriculture as in nonagriculture in the United States. While falling short of proving that $\varepsilon_a > \varepsilon_m$, the result is consistent with the idea that inputs in production are easier to substitute for each other in agriculture than in other sectors.

Third, the stock of human capital is the *only* difference between countries in the model when $\varepsilon_a > \varepsilon_m$, and A, β and γ are constant, and the agricultural productivity gap is generated by variation along this dimension alone. If the estimated λ_1 are assumed to reflect variation in A, β and/or γ, one needs a theory of why countries differ with respect to these parameters. Arguably, it could be due to frictions, such as barriers to technology transfers, or because human capital matters to innovation as suggested by many models of endogenous growth. Including one or both these options in the model will increase its complexity substantially, and it is the parsimonious option to base it on differences in elasticities instead .

5 Calibration and simulation

The model is in this section evaluated based on how well its predictions compare to the agricultural productivity gaps observed in the data. A discussed above, it is not clear which education level that should be associated with being a skilled worker. I consequently simulate two baseline scenarios. One, $S1$, in which skilled workers are defined as having completed secondary education, and another, $S1^*$, in which skilled workers are defined as having completed some tertiary education. Stars will henceforth signify that the narrow definition of skilled workers is used.

The calibrated parameter values used in the two scenarios are shown in Table 2. Following

Table 2: Calibration of baseline scenarios

Parameter name	**Symbol**	**S1**	**S1***	**Source**
EoS, nonagriculture	ε_n	1.5	1.5	Literature (see Section 2).
EoS, agriculture	ε_a	2.25	3	Estimated (see Table 1).
Land share, agriculture	α	0.18	0.18	Valentinyi and Herrendorf (2008), based on US data.
Skilled worker share, agriculture	β	0.77	0.62	Calibrated to US data (see text), depends on ε_a.
Skilled worker share, nonagriculture	γ	0.92	0.74	Calibrated to US data (see text), depends on ε_n.
Relative price of nonagricultural good	P	2.05	2.43	Calibrated to US data (see text).
Land	X	1	1	Normalized (implicitly part of P).
Relative productivity of skilled workers	A	1	1	Normalized (implicitly part of P).

the empirical literature cited in Section 2, ε_n is set to 1.5. Combined with my estimates in Table 1, it follows that $\varepsilon_a = 1.5\varepsilon_n = 2.25$ in $S1$, and $\varepsilon_a = 2\varepsilon_n = 3$ in $S1^*$.

The remaining parameters are calibrated to match data from the United States. Valentinyi and Herrendorf (2008) estimate that the income share of land in agriculture is 0.18, and α is consequently set to this value. The share parameters, β and γ, cannot easily be disentangled from the productivity parameter A. However, A can in both sectors be thought of as a part of TFP. The production function for manufacturing can, for instance, be rewritten as:

$$Y_n = P\left(\gamma A^\rho + 1 - \gamma\right)^{\frac{1}{\rho}} \left(\hat{\gamma} H_n^\rho + (1-\hat{\gamma}) L_n^\rho\right)^{\frac{1}{\rho}},$$

where $\hat{\gamma} = \frac{\gamma}{\gamma A^\rho + 1 - \gamma}$. An expression for $\hat{\beta}$ can be found in a similar way. For given elasticities of substitution, I calibrate $\hat{\gamma}$ and $\hat{\beta}$ by using information on wages and employment shares in the two sectors. In the case of nonagriculture:

$$\frac{w_H H_n}{w_L L_n} = \frac{\hat{\gamma}}{1-\hat{\gamma}} \left(\frac{H_n}{L_n}\right)^\rho \Leftrightarrow \hat{\gamma} = \frac{w_H H_n}{w_L L_M \left(\frac{H_n}{L_n}\right)^\rho + w_H H_n}. \tag{10}$$

A similar expression for the agricultural sector is used to calibrate $\hat{\beta}$.

Wage rates and employment shares are aggregated from micro level data from the American Community Survey 2010.[17] The data are summarized in the first rows of Table 3. Examples of the implied $\hat{\beta}$ and $\hat{\gamma}$ are at the bottom of the table for different values of the elasticity of substitution. $\hat{\beta}$ and $\hat{\gamma}$ converge towards $\frac{w_H}{w_L + w_H}$ (the perfect substitution case) as the elasticity

[17] Sobek *et al.* (2010).

Table 3: Wages, employment shares and implied elasticities of substitution

	Secondary edu. completed				Some tertiary edu. completed			
	H_a	H_n	w_H	w_L	H_a	H_n	w_H	w_L
US data	0.66	0.90	$38,348$	$15,000$	0.34	0.62	$22,011$	$44,694$
	$\varepsilon_a = 1$	$\varepsilon_a = 1.5$	$\varepsilon_a = 3$	$\varepsilon_a = 8$	$\varepsilon_a = 1$	$\varepsilon_a = 1.5$	$\varepsilon_a = 3$	$\varepsilon_a = 8$
Implied $\hat{\beta}$	0.83	0.80	0.76	0.73	0.51	0.56	0.62	0.65
	$\varepsilon_n = 1$	$\varepsilon_n = 1.5$	$\varepsilon_n = 3$	$\varepsilon_n = 8$	$\varepsilon_n = 1$	$\varepsilon_n = 1.5$	$\varepsilon_n = 3$	$\varepsilon_n = 8$
Implied $\hat{\gamma}$	0.96	0.92	0.84	0.77	0.77	0.72	0.71	0.68

go to infinity.

Without loss of generality, I let A and X be subsumed in P by normalizing both variables to 1. All factors affecting the relative TFP level of nonagriculture are thus summarized by P. It follows from the nomalization that $\beta = \hat{\beta}$ and $\gamma = \hat{\gamma}$, and I will henceforth drop the hat-notation.

P is, in part, endogenously determined by the elasticities, ε_a and ε_n. But P also depends on factors exogenous to the model, such as the relative demand for nonagricultural goods, and the stock of land. I therefore calibrate P to make the predictions of the model match the ratio $\frac{Y_a}{Y_n}$ in the United States. For example, high school graduates (skilled workers in $S1$) constitute 90 percent of the labor force in data from the American Community Survey. Agricultural output is 1.2 percent of nonagricultural output in the United States according to the BEA industry accounts.[18] In $S1$, P is consequently calibrated such that $\frac{Y_a}{Y_n} = 0.012$ in an economy where $H = 0.90$.

5.1 The agricultural productivity gap

The relative agricultural productivity level predicted by $S1$ is shown in Figure 3 as a function of the share of the labor force who have completed secondary education. Productivity in agri-

[18]The share of agricultural output in total output can alternatively be derived from the model as the sum of all wages paid in agriculture, corrected from the land share, divided by the sum of all wages in nonagriculture. Reassuringly, when assuming $\alpha = 0.18$ and using wage and employment data from the American Community Survey, one also ends out with $\frac{Y_a}{Y_n} = 0.012$.

culture is substantially below productivity in nonagriculture when the share of skilled workers is low. The productivity gap narrows as the share of skilled workers rise, and agricultural labor productivity eventually overtakes nonagriculture. The overtaking is a by-product of the lower labor share in agriculture (*i.e.*, $\alpha > 0$).

Data from a cross section of 106 countries are also shown in Figure 3. Each of the grey dots represent a country. Relative agricultural productivity data are from Gollin *et al.* (2014), and data for educational attainment are from Barro and Lee (2013). There is a lot of variation in the data due to country specific idiosyncrasies and measurement errors. In the model, it is assumed that every country have the same endowment of land, but population densities, climate and soil fertility differ widely in reality, and the data are not corrected for such variation. Moreover, productivity data are highly unreliable in developing countries, and may, as Herrendorf and Schoellman (2013) have shown, even be underestimated in the United States. There may also be measurement errors in the education data. The length, quality and content of secondary education varies from country to country, and the distinction between skilled and unskilled workers in the figure is therefore fuzzy.

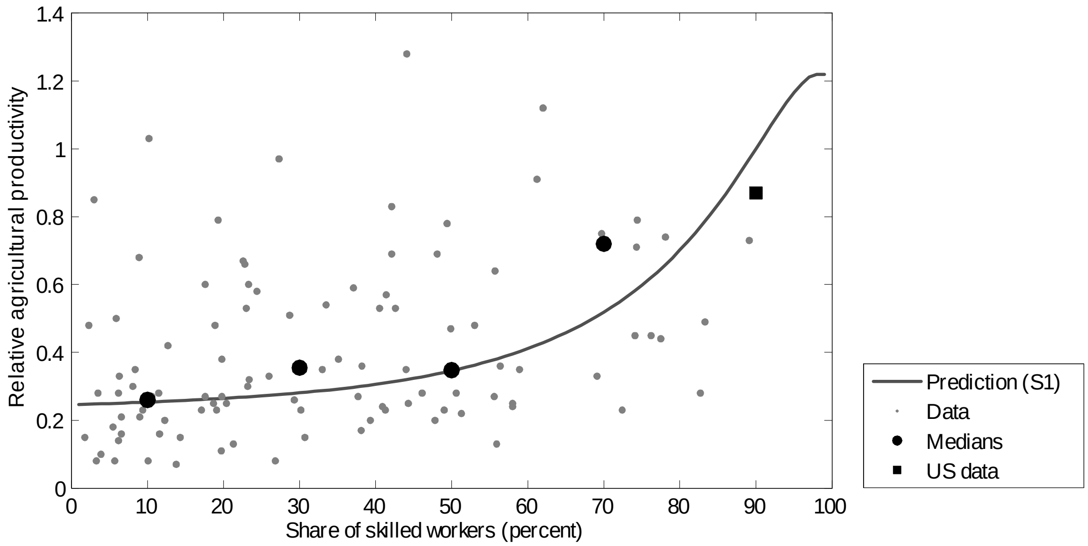
No simple model can be expected to capture all these idiosyncrasies, and I focus on the general trend in the data instead. To filter out the noise, I split the sample into countries with 0-20 percent skilled workers, 20-40 percent skilled workers, and so forth. For each group, I calculate median relative agricultural productivity. The medians are in the figure represented by a black dots at the middle of the intervals. There are too few observations with more than 80 percent skilled workers to calculate a meaningful median. Instead, the United States is highlighted by a black square.[19]

The model seems to track the general pattern in the data very well. It predicts that relative agricultural productivity is 0.26 when the share of skilled workers is 10 percent. The median in the group of countries with 0-20 percent skilled workers is 0.27. The model also conforms to the fact that relative agricultural productivity only seems to rise slowly with education levels when the initial share of skilled workers is low.

The close match between the predictions of the model and the data implies that if the

[19] To be consistent with the calibration, the United States data are based on the American Community Survey rather than data from the other sources.

Figure 3: Simulation of S1



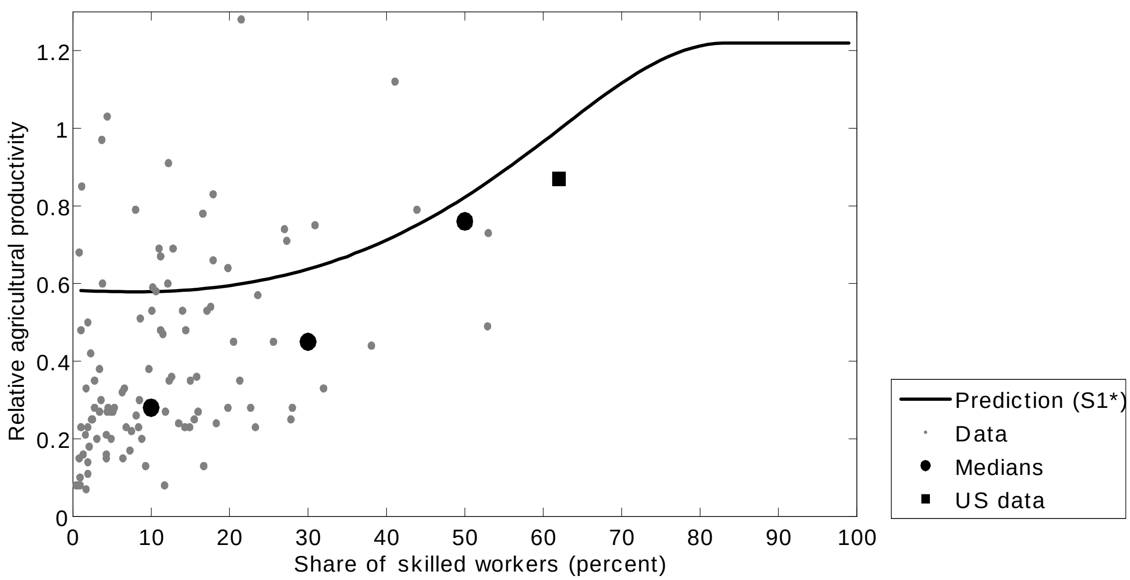
Notes: Skilled workers are defined as having completed secondary education. Productivity data are from Gollin et al. *(2014), and education data are from Barro and Lee (2013). US data are from Sobek* et al. *(2013), and the basis of the calibration. Median relative agricultural productivities are calculated for countries with 0-20, 20-40, 40-60, and 60-80 percent skilled workers respectively, and shown at the midpoint of the intervals.*

model is indeed the true model of the economy, no role is left for frictions, subsistence needs, selection, measurement errors, or other mechanisms that have been proposed in the literature as explanations for the dual economy. It is a bold claim, and it does not seem entirely plausible.

One way of reducing the predicted agricultural productivity gap is to narrow the definition of skilled workers. Using secondary education as cut-off may lead to inflated productivity gaps when the model is calibrated to the United States. The abundant supply of high school graduates in the United States means that some of them are likely to work in basic occupations where less schooling is required. Figure 4 therefore shows a simulation of $S1^*$, in which skilled workers are defined as individuals who have completed some college.

The model predicts higher relative agricultural productivity when the narrow definition of skilled workers is used. The reason is that there are fewer workers in the United States who have competed some college than workers with a high school diploma. The calibrated share parameters for skilled workers, β and γ, are consequently smaller. Lower share parameters mean that unskilled labor becomes relatively more productive, and the productivity gap between the two sectors in the model becomes smaller for a given allocation of workers. Still, a substantial part of the agricultural productivity gap is explained by the model.

Figure 4: Simulation of S1*



Notes: Skilled workers are defined as having completed secondary education. Productivity data are from Gollin et al. *(2014), and education data are from Barro and Lee (2013). US data are from Sobek* et al. *(2013), and the basis of the calibration. Median relative agricultural productivities are calculated for countries with 0-20, 20-40, 40-60, and 60-80 percent skilled workers respectively, and shown at the midpoint of the intervals.*

5.2 Decomposing the productivity gap

The size of the agricultural productivity gap is in the model driven by the share of skilled workers in the workforce through two channels: heterogenous elasticities of substitution, ε_a and ε_n, and heterogenous share parameters, β and γ. The individual roles of these two effects are illustrated in Figure 5, in which scenario $S1$ is compared to a benchmark scenario, $S0$, and to three intermediate steps $S1a$-$S1c$. The parameter values for each of these scenarios are shown in Table 4.

The agricultural sector is in the benchmark scenario, $S0$, assumed to be identical to the nonagricultural sector in terms of elasticities and the share parameters, *i.e.*, $\varepsilon_a = \varepsilon_n = 1.5$, and $\beta = \gamma$. By definition, relative agricultural productivity is constant and equal to $\frac{1}{1-\alpha}$ when the two sectors are identical.

In scenario $S1a$, ε_a is increased to $1.5\varepsilon_n = 2.25$, the value assumed in scenario $S1$. All other parameters are kept constant at the values from the benchmark scenario $S0$, so that the change reflects a *ceteris paribus* increase in the elasticity of substitution in agriculture. The same exercise is in scenario $S1b$ done for a decrease in the share parameter for skilled workers in agriculture, β. The two comparative statics are combined in scenario $S1c$. Finally, in $S1$, the price level P is allowed to respond endogenously to the changes in the other parameters, and the calibrated β is likewise allowed to be affected by the higher ε_a as in Equation (10).

The relative productivity levels predicted by these scenarios show that both a higher elasticity of substitution in agriculture (scenario $S1a$), and a lower share parameter for skilled workers in agriculture (S1b), cause significant productivity gaps in agriculture. The gaps are of similar size when the share of skilled workers in the labor force is low, but, in the case of heterogenous elasticities, it is quickly reduced as the number of skilled workers rises. In fact, agriculture overtakes nonagriculture briefly in scenario $S1a$, since a higher elasticity of substitution, *ceteris paribus*, increases the marginal product of skilled workers when they constitutes a large fraction of the labor input.[20]

The predicted agricultural productivity gap becomes larger when the two mechanisms are combined, as in scenario $S1c$. Individually, a lower share parameter in agriculture, and a higher elasticity in agriculture, predict a relative agricultural productivity level slightly above 0.4 in a country with very few skilled workers. Combined, they predict a relative productivity level slightly above 0.2. The two mechanisms should thus be seen as complementary rather than competing explanations for the dual economy.

[20] Formally, the relative marginal products of the two types labor is equal to the skill premium, which in $S1a$ is given by $\frac{w_H}{w_L} = \frac{\beta}{1-\beta}\left(\frac{H_i}{L_i}\right)^{-\frac{1}{\varepsilon_i}}$, $i = a, n$. Unskilled labor is employed in both sectors, and the skill premium determines the allocation of skilled workers.The skill premium is higher in agriculture than in nonagriculture when $\frac{H_a}{L_a} = \frac{H_n}{L_n} > 1$ and $\varepsilon_a > \varepsilon_n$. Labor market mobility equalizes skill premia across sectors, and the human capital intensity in agriculture, $\frac{H_a}{L_a}$, must therefore be above that of nonagriculture, $\frac{H_n}{L_n}$. Productivity in agriculture is consequently higher than in nonagriculture if the share of skilled workers in the total labor force is high.

Table 4: Calibration of scenarios shown in Figure 5 and Figure 6

Parameter name	Symbol	S0	S1a	S1b	S1c	S0*	S1a*	S1b*	S1c*
EoS, nonagriculture	ε_n	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
EoS, agriculture	ε_a	1.5	2.25	1.5	2.25	1.5	3	1.5	3
Land share, agriculture	α	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
Skilled worker share, agriculture	β	0.92	0.92	0.80	0.80	0.74	0.74	0.53	0.53
Skilled worker share, nonagriculture	γ	0.92	0.92	0.92	0.92	0.74	0.74	0.74	0.74
Relative price of nonagricultural good	P	2.66	2.66	2.66	2.66	2.84	2.84	2.84	2.84
Land	X	1	1	1	1	1	1	1	1
Relative productivity of skilled workers	A	1	1	1	1	1	1	1	1

In $S1c$, the parameters P and γ are kept fixed at the calibrated levels from $S0$ and $S1b$ respectively, whereas they are allowed to vary with assumptions about other parameters in the baseline scenario $S1$. A comparison between the curves for $S1c$ and $S1$ in Figure 6 shows that the quantitative results of the model is not driven by this parameter flexibility.

Figure 5: Decomposition of S1

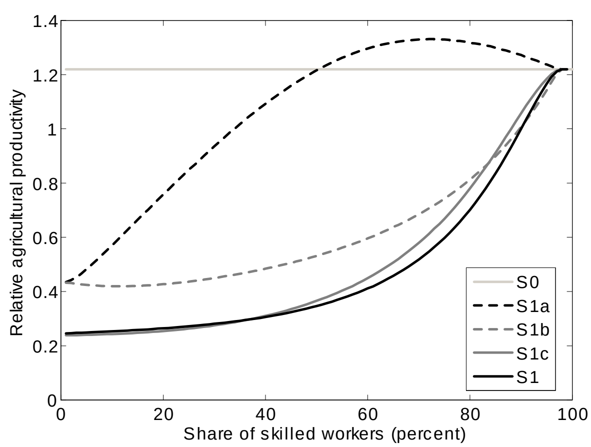
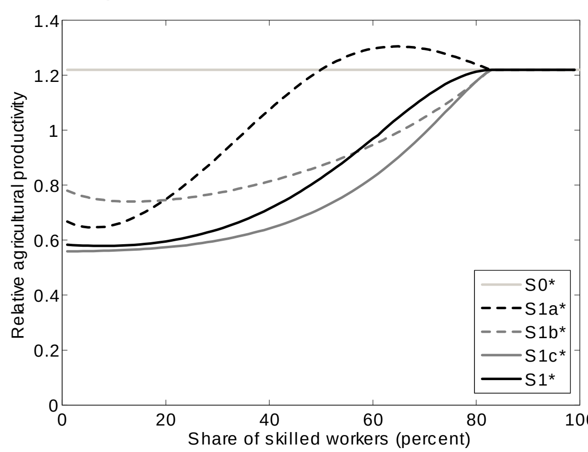


Figure 6: Decomposition of S1*



The results from a decomposition of the scenario $S1^*$, where the narrow definition of skilled workers is used, are similar (Figure 6). Without heterogenous elasticities of substitution, the model predicts a relative agricultural productivity level of 0.74 when the share of skilled workers is 10 percent, whereas the baseline scenario with heterogenous elasticities yields a relative productivity level of 0.58. So, while the predicted gap is smaller than in the case with secondary education used as skill cut-off, the portion of the gap accounted for by the heterogenous elasticities is larger.

5.3 Comparative statics

The switch from the broad to the narrow definition of skilled workers (Figure 3 vs. Figure 4), and the decomposition of the gap in the previous subsection, were essentially comparative statics with respect to the input shares, β and γ, and the elasticity ε_a. Comparative statics with respect to the remaining parameters are reviewed in this subsection, starting with the elasticity of substitution in nonagriculture.[21]

The effect of a higher ε_n is illustrated in Figure 7. In a new scenario, $S2$, ε_n is changed from 1.5 to 2, corresponding to the highest empirical estimates of the aggregate elasticity found in the literature. The ratio $\frac{\varepsilon_a}{\varepsilon_n}$ is kept constant at 1.5, as in the benchmark scenario. A higher elasticity of substitution in nonagriculture implies a higher relative agricultural productivity level for a given value of H. The reason is that substitutability makes output less sensitive to the composition of the labor force, and the productivity loss from having fewer skilled workers in agriculture is therefore smaller.

Scenario $S3$ in Figure 7 shows the opposite situation. ε_m is now changed to 1, corresponding to a Cobb Douglas function. The agricultural productivity gap becomes larger in countries with few skilled workers as a consequence.

Figure 7: Sensitivity to EoS

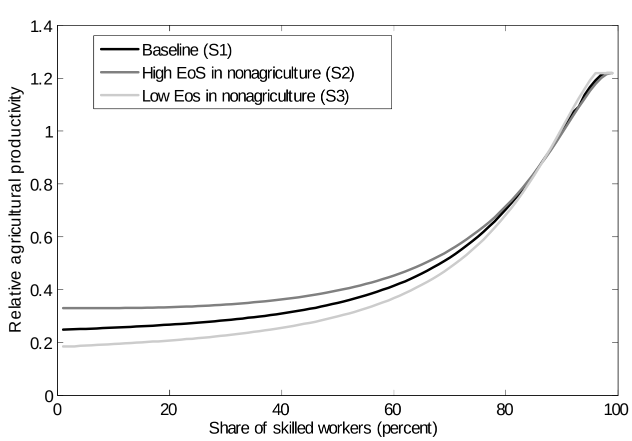
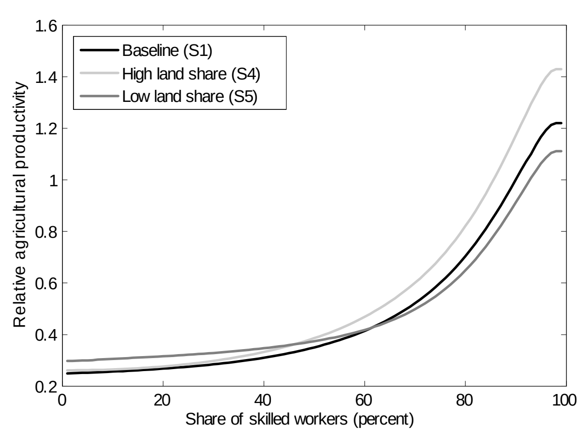


Figure 8: Sensitivity to land share



This paper is concerned with *labor* productivity, and a *ceteris paribus* change in the land

[21] Se Table 5 for the calibrations used in this subsection

share α will, for a given share of skilled workers, result in a proportional change in labor productivity in agriculture. However, the calibration strategy means that the relative price of nonagricultural goods, P, is positively related to the value of α.[22] Figure 8 show comparative statics with respect to the land share in the case where P is allowed to respond endogenously to these changes. α is in two new scenarios set to 0.1 and 0.3 respectively, as opposed to 0.18 in the baseline scenario.

The relative agricultural productivity level is, by construction, equal to $\frac{1}{1-\alpha}$ when the share of skilled workers is so high that some of them are employed in jobs where their skills are not essential. Formally, when $w_H = w_L = w$, profit maximization in agriculture leads to the following relationship: $w\left(H_a + L_a\right) = (1-\alpha)\, Y_a$. Since labor is the only factor of production in nonagriculture, we have that $w\left(H_n + L_n\right) = Y_n$. By combining these expressions, the relative agricultural labor productivity can be derived as $\frac{1}{1-\alpha}$. Consequently, as shown in Figure 8, P matters little when the share of skilled workers is high, and a change in α translates directly into a proportional change in relative agricultural productivity.

P is important when the share of skilled workers is low. P is 1.48 when $\alpha = 0.1$, as opposed to 2.05 in the baseline scenario. A low relative price of nonagricultural goods explains why the scenario with a low α leads to higher relative agricultural productivity than the others for low shares of skilled workers. But in any case, the predictions of the model are not particularly sensitive to the assumption made about α.

6 Agricultural employment and the skill premium

The model is now evaluated along two other dimensions than productivity: the agricultural employment share, and the relative wage rate of skilled workers.

How much the dual economy structure matters for aggregate productivity depends on the size of the agricultural sector. It would matter little in developing countries, if agriculture did

[22]Recall that P is calibrated to match the ratio of agricultural output to nonagricultural output in the United States. Real agricultural output is positively related to α, and the relative price P will therefore have to be higher to keep the output ratio (measured in nominal terms) fixed at the level observed in the United States.

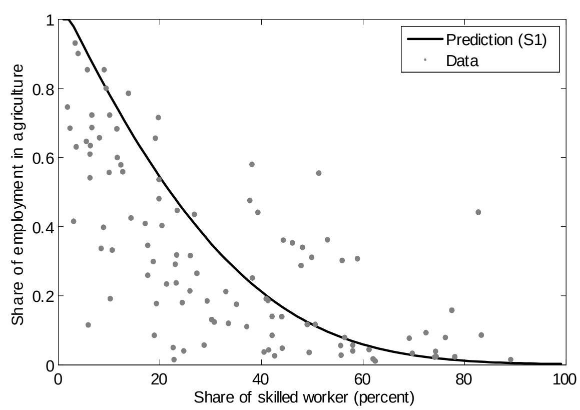
Table 5: Calibration of scenarios shown in Figure 7 and Figure 8

Name	**Symbol**	**S1**	**S2**	**S3**	**S4**	**S5**
EoS, nonagriculture	ε_n	1.5	2	1	1.5	1.5
EoS, agriculture	ε_a	2.25	3	1.5	2.25	2.25
Land share, agriculture	α	0.18	0.18	0.18	0.3	0.1
Skilled worker share, agriculture	β	0.77	0.76	0.80	0.77	0.77
Skilled worker share, nonagriculture	γ	0.92	0.89	0.96	0.92	0.92
Relative price of nonagricultural good	P	2.05	2.10	1.99	3.66	1.48
Land	X	1	1	1	1	1
Relative productivity of skilled workers	A	1	1	1	1	1

not play such a big role in their economies. And important task for any dual economy model is to replicate this fact.

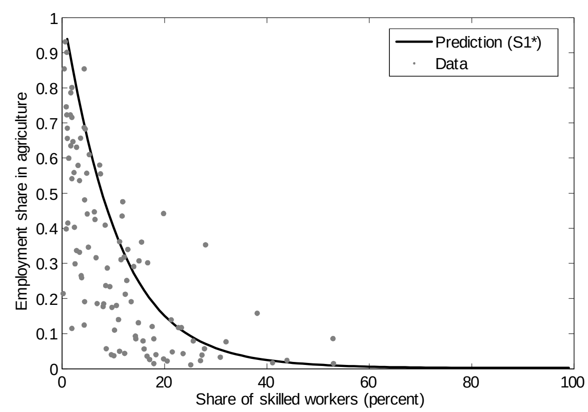
Figure 9 and Figure 10 show the predicted agricultural employment as a share of total employment in the two baseline scenarios $S1$ and $S1^*$. The predictions are consistent with the stylized empirical facts. Poor countries with low human capital stocks have a high fraction of their workforces employed in agriculture, whereas agriculture is a minor sector in developed countries with high education levels. Both scenarios predict a somewhat higher agricultural employment share than in most countries in the data (represented by dots in the figures), but the predictions are still within empirically reasonable values.

Figure 9: Agricultural employment S1



Notes: Skilled workers have completed secondary education. Data are from Gollin et al. *(2014).*

Figure 10: Agricultural employment S1*



Notes: Skilled workers have completed some tertiary education. Data are from Gollin et al. *(2014).*

Turning to the return to education, it is convenient to restate the wage premium of being a skilled worker as it is given by the model:

$$\frac{w_H}{w_L} = \frac{\beta}{1-\beta}\left(\frac{H_a}{L_a}\right)^{-\frac{1}{\varepsilon_a}} = \frac{\gamma}{1-\gamma}\left(\frac{H_n}{L_n}\right)^{-\frac{1}{\varepsilon_n}}. \tag{11}$$

Relative wages depend on the input shares of skilled workers, and, unless they are perfect substitutes in production, on the relative supply of the two types of workers.

Figure 11 and Figure 12 plot the skill premia implied by the two baseline scenarios. The skill premium is lower when skilled workers are defined as having completed some tertiary education. Since this group is smaller than the group of workers with secondary education, the calibrated values of β and γ become smaller, implying a lower input share of skilled workers. The relative input shares, $\frac{\beta}{1-\beta}$ and $\frac{\gamma}{1-\gamma}$, correspond to productivity advantages of skilled workers. And, as Equation (11) shows, such productivity advantages directly affect the skill premium.

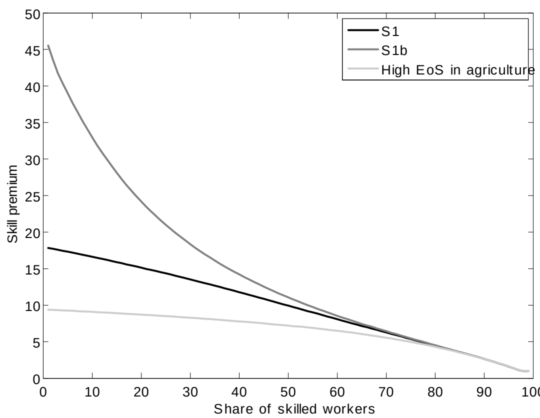
The input shares β and γ are calibrated to match data on wages and employment in the United States. The predicted skill premium in a country with the same share of skilled workers as the United States will therefore correspond to what is observed in the American Community Survey used in the calibration. A reasonable test of the model is how well it predicts the skill premium "out of sample", *i.e.*, how well its predictions compare to the data from countries with low levels of human capital.

An individual with at least secondary education can, according to the simulation of $S1$, earn an annual income up to 17 times higher than an individual with primary schooling, or less, when the human capital stock is sufficiently low. The corresponding number is around 10 in the case of $S1^*$. These magnitudes do not seem implausible in a developing country where a substantial fraction of the population survives for less than a dollar per day. The mincerian returns implied by the simulations are, however, in the 25-35 percent range if skilled workers are assumed to have eight years more schooling than unskilled workers. The mincerian returns found in the empirical literature are usually smaller: 10 percent per annum, with only a slight tendency to higher returns in countries with low education levels.[23]

The discrepancy is, however, substantially smaller in the baseline scenario with heterogeneous elasticities of substitution, than when it is assumed that $\varepsilon_a = \varepsilon_n$. This is illustrated in Figure 11 by the curve representing scenario $S1b$ from Section 5.2. The implied mincerian

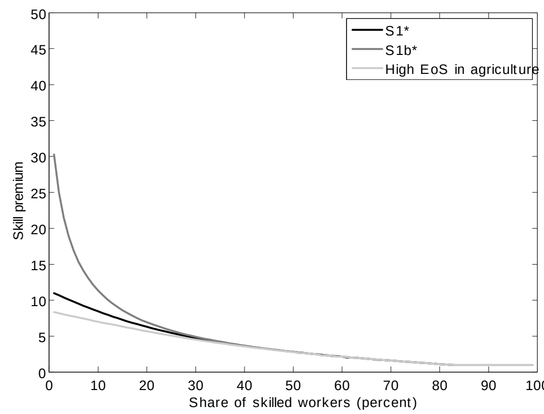
[23] See, *e.g.*, Banerjee and Duflo (2005).

Figure 11: Skill premium S1



Notes: Skilled workers have completed secondary education.

Figure 12: Skill premium S1*



Notes: Skilled workers have completed some tertiary education.

returns of this scenario are above 45 percent when the share of skilled workers is low. A corresponding scenario $S1b^*$ is shown in Figure 12.

Intuitively, in an economy with a high employment share in agriculture, the economy-wide elasticity of substitution between the two types of workers will be close to the one in the agrarian sector. A low level of ε_a, as in $S1b$, will consequently translate into a relatively high skill premium in countries with few skilled workers. Conversely, an economy with a negligible employment share in agriculture will have an economy-wide elasticity of substitution close to the one in the nonagrarian sector. This mechanism allows the model parameters to conform to the empirical estimates of the aggregate elasticity of substitution between skilled and unskilled workers in developed economies, while making more realistic predictions about the skill premium in developing countries than a model without the mechanism.

Increasing the relative elasticity of substitution in agriculture beyond what is assumed in $S1$ and $S1^*$ reduce the gap between the model and the empirical estimates of the mincerian returns further. The effect is shown in Figure 11 and Figure 12 by the curves labelled High EoS in agriculture. They represent simulations of scenarios identical to $S1$ and $S1^*$, except that the elasticity of substitution in agriculture is now assumed to be three times higher than the one in nonagriculture.

Still, the model predicts too high skill premia if the close-to-constant mincerian returns are taken at face value. Part of this gap is related to the calibration. The United States is one of the countries in the OECD with the highest returns to education, and calibrating to another OECD country will reduce the predicted skill premium.[24] Moreover, the skill premium used in the calibration is based on annual wages, and is thereby inflated by the fact that workers with less education work fewer hours.

The gap may also be bridged from the empirical side. Several studies have shown that poor countries also tend to have poor schools, and correcting the mincerian returns from this empirical fact will lead to higher, quality-adjusted returns to education in developing countries.[25] As the model assumes uniform schooling, such effects should be taken into account when its predictions are compared to the data.

The apparent constancy of mincerian returns across countries may also be slightly misleading. Psacharopoulos and Patrinos (2004), show, for instance, that the average private return from investing in primary schooling is 23-26 percent no matter the income level of the country. The return to higher education, on the other hand, drops with income. They find a private return of 26 percent from investing in higher education in the poorest countries in their sample, whereas the return is 12 percent in the group of rich countries. Such differences may not show up in estimated average mincerian returns for all years of schooling, since most of the labor force in developing countries do not attain higher education. Average mincerian returns for these countries will therefore be biased towards the return to primary education, whereas average mincerian returns will be biased towards the return to secondary and tertiary education in countries where most workers are highly educated.

In conclusion, the relative high returns to schooling predicted by the model should not be taken as evidence against it. On the contrary, for realistic values of the aggregate elasticity of substitution in developed countries, the model predicts more plausible values of the skill premium in developing countries than a model where the elasticity is assumed to be identical across sectors.

[24] OECD (2013), Table A6.1.

[25] See, *e.g.*, Schoellman (2012) and Kaarsen (2014).

7 Taking Stock

I have in this paper shown that the elasticity of substitution is greater in agriculture than in nonagriculture, and I have, based on this insight, developed a model in which sector sizes, the allocation of human capital, and sectoral productivity levels are pinned down by the share of skilled workers in the labor force. Calibrated to the United States, the model is able to generate sizable agricultural productivity gaps when the share of skilled workers in the labor force is low.

The relative productivity levels are driven by a comparative advantage of skilled workers in agriculture, and by heterogenous elasticities of substitution across sectors. Individually, both mechanisms cause a low relative agricultural productivity level when the stock of skilled workers is low. Combined, they reduce relative agricultural productivity even further.

The size of the agricultural productivity gap predicted by the model depends on the definition of skilled workers. When skilled workers are defined as having completed secondary education, the model predicts relative agricultural productivity levels as low as 0.2, a level that conforms with the ones observed in developing countries. By implication, no role is left for frictions, subsistence needs, selection, or other mechanisms that have been proposed in the literature as explanations for the dual economy. Setting the cut-off for skilled workers at secondary education may, however, lead to inflated productivity gaps when the model is calibrated to the United States. The high supply of high school graduates in the United States means that many of them are likely to work in basic occupations where less schooling is required.

An alternative calibration, where the definition of skilled workers is narrowed to cover only individuals who have completed some college, yields relative agricultural productivity gaps slightly below 0.6 in countries where human capital is scarce. This result is more in line with Gollin *et al.* (2014), who estimate that roughly one third of the agricultural productivity gap can be explained by the allocation of human capital.

The calibration based on tertiary education may, however, also be inadequate. Being in short supply, high school graduates in many developing countries may land jobs with a high skill requirement. Moreover, educational systems differ, and vocational training and technical secondary programs that provides student with specific skills are common in many countries outside the United States. The role of human capital allocation may therefore be understated when college is a requirement for being a skilled worker. A reasonable conjecture is therefore that human capital differences cause relative agricultural productivity to be between 0.2 and 0.6 in developing countries, and perhaps closer to the upper bound of the range.

That is somewhat bigger role for human capital than what Gollin *et al.* (2014) find. However, their estimate is based on mincerian returns to education that show very little cross country variation, and it is implicitly assumed that the return to a year of schooling within a country is the same at all levels of educational attainment. As argued in Section 6, Gollin *et al.* (2014) may therefore underestimate the role of human capital, as the return to achieving the education levels that define skilled workers in the model are not fully captured by mincerian returns.

In general, many of the variables involved are hard to measure and compare across countries. Productivity data are highly unreliable in developing countries, and it is difficult to make a distinction between skilled and unskilled workers that is valid globally, since both the structure and quality of education systems differ widely. But all things considered, heterogenous skill complementarities seem to be a simple, empirically relevant, and quantitatively important explanation for the dual economy phenomenon. Moreover, the absence of frictions in the model imply that the dual economy is a Pareto optimal equilibrium outcome. This is not to say that factor market distortions or externalities necessarily are unimportant in the dual economies of the real world, or that government intervention is pointless. But the inefficiencies that need to be addressed by policy makers may be a lot smaller that what a benchmark model without sectoral differences in skill complementarity would suggest.

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Data Appendix

The data used in the regressions reported in Table 1 are shown below. The numbers are calculated by the author based on national census data from the IPUMS-International database, collected by Sobek *et al.* (2013). The newest census (at the time of writing) in the database is used in each country. Agriculture include fishing and forestry. Individuals not in employment, or with no information on educational attainment, are excluded from the sample. The sample only includes persons of 15 years of age or older. Countries with missing information on one or more of there relevant parameters are excluded. Three definitions of skilled workers are used: individuals with secondary education (skill 1), individuals with technical secondary education or some tertiary education (skill 2), and individuals with some tertiary education (skill 3).

		Skill 1		Skill 2		Skill 3				Skill 1		Skill 2		Skill 3	
Country	Year	H_a	H_n	H_a	H_n	H_a	H_n	Country	Year	H_a	H_n	H_a	H_n	H_a	H_n
Austria	2001	0.69	0.78	0.68	0.73	0.01	0.08	Fiji	2007	0.15	0.50	0.03	0.26	0.00	0.06
Bolivia	2001	0.06	0.41	0.01	0.18	0.01	0.08	France	2006	0.33	0.51	0.12	0.32	0.12	0.32
Brazil	2010	0.12	0.51	0.02	0.15	0.02	0.15	Germany	1987	0.32	0.31	0.30	0.26	0.01	0.08
Cambodia	2008	0.02	0.17	0.00	0.06	0.00	0.04	Ghana	2000	0.04	0.19	0.03	0.14	0.00	0.02
Cameroon	2005	0.04	0.22	0.01	0.07	0.01	0.05	Greece	2001	0.19	0.68	0.06	0.39	0.02	0.26
Canada	2001	0.58	0.80	0.38	0.60	0.12	0.26	Haiti	2003	0.01	0.28	0.01	0.24	0.00	0.02
Chile	2022	0.17	0.53	0.05	0.23	0.02	0.08	Hungary	2001	0.61	0.81	0.41	0.47	0.07	0.19
China	1990	0.04	0.34	0.00	0.13	0.00	0.02	India	2004	0.11	0.35	0.02	0.15	0.02	0.12
Colombia	2005	0.08	0.48	0.02	0.22	0.01	0.15	Indonesia	2010	0.10	0.47	0.02	0.18	0.00	0.09
Costa Rica	2000	0.06	0.39	0.02	0.19	0.01	0.15	Iran	2006	0.10	0.41	0.03	0.23	0.01	0.16
Cuba	2002	0.28	0.64	0.17	0.42	0.03	0.17	Iraq	1997	0.07	0.32	0.05	0.27	0.02	0.12
Ecuador	2010	0.13	0.54	0.02	0.17	0.01	0.15	Ireland	2006	0.45	0.73	0.16	0.40	0.06	0.27
Egypt	2006	0.26	0.62	0.03	0.28	0.02	0.22	Israel	1995	0.60	0.78	0.16	0.37	0.08	0.21
El Salvador	2007	0.04	0.34	0.01	0.12	0.01	0.08	Italy	2001	0.22	0.55	0.07	0.20	0.02	0.12

		Skill 1		Skill 2		Skill 3				Skill 1		Skill 2		Skill 3	
Country	Year	H_a	H_n	H_a	H_n	H_a	H_n	Country	Year	H_a	H_n	H_a	H_n	H_a	H_n
Jamaica	2001	0.34	0.67	0.00	0.04	0.00	0.04	Rwanda	2002	0.00	0.16	0.00	0.03	0.00	0.02
Jordan	2004	0.30	0.58	0.08	0.23	0.07	0.21	Saint Lucia	1991	0.08	0.36	0.01	0.09	0.01	0.03
Kyrgyz Rep.	2009	0.85	0.87	0.08	0.36	0.04	0.25	Sierra Leone	2004	0.00	0.07	0.00	0.07	0.00	0.03
Malawi	2008	0.04	0.22	0.00	0.02	0.00	0.02	Slovenia	2002	0.53	0.84	0.38	0.52	0.02	0.13
Malaysia	2000	0.02	0.17	0.01	0.13	0.01	0.13	South Africa	2007	0.23	0.51	0.03	0.09	0.03	0.09
Mali	1998	0.00	0.06	0.00	0.05	0.00	0.01	Spain	2001	0.15	0.49	0.09	0.36	0.02	0.12
Mexico	2010	0.07	0.40	0.02	0.23	0.02	0.16	South Sudan	2008	0.01	0.06	0.01	0.05	0.00	0.02
Mongolia	2000	0.17	0.70	0.01	0.23	0.01	0.23	Sudan	2008	0.01	0.11	0.01	0.10	0.01	0.09
Morocco	2004	0.02	0.20	0.00	0.06	0.00	0.06	Switzerland	2000	0.94	0.94	0.65	0.75	0.02	0.10
Nicaragua	2005	0.04	0.35	0.01	0.15	0.01	0.11	Tanzania	2002	0.02	0.23	0.00	0.02	0.00	0.02
Palestine	2007	0.17	0.43	0.02	0.19	0.02	0.19	Thailand	2000	0.04	0.37	0.01	0.22	0.00	0.10
Panama	2010	0.11	0.59	0.03	0.23	0.02	0.21	Turkey	2000	0.06	0.44	0.02	0.25	0.01	0.18
Peru	2007	0.24	0.74	0.06	0.40	0.02	0.17	Uganda	2002	0.02	0.25	0.01	0.18	0.00	0.04
Philippines	2000	0.20	0.62	0.02	0.21	0.01	0.14	United States	2010	0.66	0.90	0.11	0.29	0.11	0.29
Portugal	2001	0.07	0.30	0.02	0.13	0.02	0.13	Uruguay	2006	0.18	0.42	0.12	0.27	0.03	0.09
Puerto Rico	2005	0.39	0.84	0.05	0.27	0.05	0.27	Venezuela	2001	0.07	0.43	0.01	0.09	0.00	0.00
Romania	2002	0.35	0.83	0.32	0.73	0.02	0.15	Vietnam	2009	0.09	0.31	0.01	0.16	0.00	0.14

Irrigation and Autocracy

Jeanet Sinding Bentzen Nicolai Kaarsen Asger Moll Wingender

Abstract

Irrigated agriculture has traits that the resource curse literature associate with rent-seeking and poor institutional outcomes. These include spatial concentration, high yields, and dependence on a controllable water source. We hypothesize that regions with a long history of irrigation-based agriculture are more likely to be autocratic today than regions with rainfed agriculture. The hypothesis is confirmed empirically. To deal with endogeneity, we use an exogenous measure of how much irrigation potentially can increase yields above the yields obtained from rainfed agriculture. At the national level, we show that areas with a higher irrigation potential are more likely to be ruled by an autocratic regime today. At the subnational level, including country-fixed effects, we find that irrigation potential is associated with less favorable views on democracy. Last, we find that premodern societies, surveyed by ethnographers, were more likely to develop a hierarchy based on elite stratification if their agriculture was based on irrigation.

1 Introduction

Only in the poorest developing countries is agricultural production still the most important source of income today. Yet, in a historical perspective, most countries have until very recently been agrarian economies, and their institutions have been shaped by the fact. We argue that the source of water for agriculture in a society is crucial for the development of institutions in the society, and that these institutions persist even after agriculture ceases to be the main economic activity.

Crops are grown using rain water, water from man-made irrigation systems, or a combination of the two. Rain is spread evenly over vast areas. Irrigation, on the other hand, depends on a water source such as a nearby river. Irrigated agriculture therefore tends to be concentrated in smaller areas than rainfed agriculture, and the allocation of water can be controlled by dams, canals, and other forms of irrigation infrastructure. Moreover, irrigation allows for more intensive agriculture than otherwise possible, and may permit multiple harvests per year in warm climates. Spatial concentration, high value, and ease of control makes rent-seeking both feasible and economically attractive. Resources with these attributes are classified as "point-source" resources in the resource curse literature, and often associated with poor institutional outcomes, oligarchic politics, and autocracy.[1]

The most notable examples of point-source resources are oil and minerals. While irrigated agriculture arguably is less "pointy" than oil and minerals, it still provides a better target for rent-seeking than rainfed agriculture. We hypothesize that irrigation increased the power of the political and economic elites, who consequently were in a position where they had the incentives and the means to oppose democracy in order to protect their privileges. That made democratic institutions less likely to emerge in regions dependent on irrigation than in regions where agriculture is rainfed.

The hypothesis is about the water source, not the types of crops involved. It is, however, related to Engerman and Sokoloff (1997, 2000, 2002, 2005), who argue that suitability for plantation crops (*e.g.*, sugar, bananas, and cocoa) made slavery attractive in the tropical Americas. Their argument is essentially that plantation crops are point-source resources, although they do not use that term explicitly. The temperate parts of the Americas were more suitable for cereals, and cereal production provided the basis for egalitarian societies based on independent farmers.[2] Slavery, on the other hand, created a marked inequality in the distribution of power that did not end with the emancipation. This difference put the two parts of the continent on different development trajectories.

The idea that irrigation leads to poor institutional outcomes is not new. The link be-

[1] *E.g.*, Auty (2001), Ross (2001, 2012), Isham *et al.* (2005), Bulte *et al.* (2005), Boschini *et al.* (2007), and Williams (2011).

[2] The ideas of Sokoloff and Engerman was anticipated by Baldwin (1956) and Earle (1978), and later generalized by Easterly (2007).

tween irrigation and repressive institutions was noted by Adam Smith, John Stuart Mill, and Karl Marx, but it is perhaps most forcefully articulated by Karl August Wittfogel in *Oriental Despotism*.[3] Wittfogel gives ancient Egypt, Mesopotamia, India, China, and the Andean and Mexican civilizations as examples of despotic regimes underpinned by irrigation.[4] *Oriental Despotism* has been hotly debated and is routinely dismissed by anthropologists and historians.[5] The criticism of Wittfogel's theoretical framework may be justified, but we confirm that he was right about the basic empirical link between irrigation and autocracy.[6] We are, to our knowledge, the first to test the theory using statistical methods.

Actual irrigation is likely to be endogenous. For instance, more developed societies are potentially more likely to have developed irrigation, while development at the same time may also influence the degree of democracy adopted by the society. To overcome endogeneity, we use a measure of irrigation *potential* based on exogenous geographical and climatic variables. The available quantitative information on the extent of historical irrigation is limited, and we treat irrigation potential as a proxy for historical irrigation in our main regressions. We do, however, confirm our results using our measure of irrigation potential as an instrument for actual current irrigation, and for the limited historical irrigation data we have.

We show that countries with a high irrigation potential are more likely to be autocratic today as measured by various indices of democratic institutions, such as the Polity IV index. At the subnational level, we show that respondents in the World Values Survey have a less favorable view on democracy if they live in districts with high irrigation potential. The link between irrigation and institutions is also confirmed in premodern societies surveyed by ethnographers.[7]

[3]Smith (1776) book IV, chapter IX, Mill (1848) p. 20-21, Marx (1853), and Wittfogel (1957). While irrigation is not mentioned explicitly, Smith (1776) discusses the differences between Europe and the great irrigation-based civilizations in Egypt, India, and China.

[4]Wittfogel (1957) p. 24.

[5]See, *e.g.*, Toynbee (1958), Leach (1959), Needham (1959), Mann (1986), or Fukuyama (2011).

[6]There is a large literature on irrigation and autocracy based on case studies. Examples are Leach (1959) and Toynbee (1958) along with numerous others. See Mitchell (1973) and Hunt and Hunt (1976) for reviews of the literature. Wittfogel's claim that irrigation was a cause of state formation has been refuted by anthropologists and archaeologists who have shown that the emergence of the state preceeded large scale irrigation by centuries, even millenia. See, *e.g.*, Carneiro (1970). The hypothesis we investigate is not about the origin of the state. It is about whether areas with irrigation based agriculture are more autocratic today.

[7]This part of the analysis is based on the Ethnographic Atlas compiled by Murdock (1967).

The results are robust to a wide range of control variables capturing variation in geography, climate, resource endowments, development, religion, and colonial history. The latter is shown to dilute the effect of irrigation, consistent with the large literature documenting that European presence had a long-lasting impact on institutions.[8]

The paper is organized as follows. In Section 2, we review the theoretical link between irrigation and present-day institutions. Section 3 describes the methodological approach used in the empirical analysis with emphasis on our measure of irrigation potential. We proceed to test the link between irrigation and autocracy at the country level in Section 4, and at a more disaggregated level in Section 5. Section 6 concludes.

2 The hypothesis

The concept of oriental despotism has existed in one form or another in the European intellectual discourse for millennia. Aristotle, Herodotus, Montesqieu, and Hegel, to name a few, all considered Middle Eastern and Asian institutions less representative and more despotic than what they were used to in their native European countries. Karl Marx attributed the observation to what he called the Asiatic Mode of Production and, inspired by Adam Smith and other classical economists, argued that the ability to control water was one reason for the state's dominance in the irrigation dependent societies in Asia.[9] Expanding on their analysis, Wittfogel (1957) developed a theory of *hydraulic societies*, explicitly linking oriental despotism to large-scale irrigation systems.[10]

Wittfogel argues that the construction and maintenance of large-scale irrigation systems required a strong leadership that gradually evolved into despotic states. The control of water made it possible for the despot to increase suppression of the populace to levels unknown in Europe without fearing revolt. Wittfogel's account of oriental despotism is as sprawling as it

[8] *E.g.*, Acemoglu *et al.* (2001), Feyrer and Sacerdote (2009), Olsson (2009), Dell (2010) and Hariri (2012).

[9] Marx (1853). See O'Leary (1989) for an account of the history of thought on the asiatic mode of production.

[10] The hydraulic society should be distinguished from what Wittfogel (1957) called hydroagriculture. The difference is a matter of scale. In the hydraulic society, farmers are dependent on a common irrigation system of canals and dams. In hydroagriculture, farmers depend on irrigation, but the geographical conditions make coordination unneccessary or impossible. Wittfogel mentions Japan as an example of the latter. For further discussion, see Price (1994).

is speculative. But it does convey one powerful idea that resonates with the modern literature of the resource curse: valuable and easily controlled resources tend to end up in the hands of a ruling elite, which use the resources to entrench their power further.

2.1 Irrigation as a point-source resource

Irrigation becomes attractive when the amount of rain is scarce and fertile arable land readily available, i.e., when the naturally occurring supply of water in the fields falls short of demand. Irrigation is feasible when a steady water source, such as a river or a lake, exists and when irrigation infrastructure to control the water is built. High value and controllability is exactly what defines a point-source resource, and irrigated agriculture is thus an attractive target for rent-seeking for the same reasons as oil, minerals, and diamonds.

The gain in agriculture from irrigation can be substantial. Fresh water can turn otherwise barren land into fertile fields. River water is particularly beneficial, since it is rich in nutrients and silt. In warmer climates, irrigation can allow for multiple harvests every year, where none was possible before. Still, agriculture may not provide as high rents as oil or diamonds. But total agricultural production has by far outstripped mining output throughout human history, and it still does so in most countries today. The scope for rent-seeking in agriculture may therefore be higher, although the rents per production unit may be lower than in mining. The potential for irrigation to have the same negative effect on institutions should, by implication, be as quantitatively important as it has been shown to be the case for other point-source resources.[11]

A small note on irrigation technology is warranted here. New technologies have reduced the relative cost of irrigation and many areas today are equipped for irrigation, although it only provides a slight increase in yields compared to rainfed conditions. Furthermore, the possibility of pumping ground water from aquifers has presumably made irrigation more diffuse than it was historically, where it almost exclusively relied on a visible water source and canals, dams, and similar infrastructure. Our hypothesis is not related to more recent irrigation techniques. We discuss this issue at further length in Section 3, where we introduce our measure of irrigation

[11] *E.g.*, Ross (2001), Isham *et al.* (2005), Bulte *et al.* (2005), Boschini *et al.* (2007), and Williams (2011).

potential. In what follows, we use the term irrigation as shorthand for traditional irrigation methods.

2.2 Amplifying mechanisms

Apart from being a point-source resource, irrigation differs from rainfed agriculture in other aspects that tilt power in favor of a rent-seeking elite at the expense of independent farmers. Irrigation systems resemble a public good, and construction and maintenance is often expensive. Local land lords or centralized governments are therefore in a better position to finance the construction of irrigation systems than individual farmers, and consequently to claim ownership to them. That conclusion was also drawn by the geographer Commodore B. Fisher who, observing early 20$^{\text{th}}$ century Persia, noted that:

> *"Because of the expense and the difficulty of cooperative effort on the part of small landowners, these irrigation systems are privately owned and tend to perpetuate the feudal system which is well organized in Persia today. A wealthy family can purchase an extensive tract of desert land, make a large investment in a water system, and attract hundreds of tenants who are eager to make their homes around the water supply. Under the need of water and the difficulty of securing it, these tenants are easily reduced to virtual slavery."*[12]

Admittedly, irrigation systems can be built and maintained in a completely decentralized fashion as Ostrom (1990) shows. Although exceptions can be found, such arrangements are inherently unstable due to the bargaining process involved and tend to be short-lived compared to centralized systems.[13] Rent-seeking elites may also be tempted to claim ownership of decentralized irrigation systems, especially when existing property rights are insecure.

The ability to monitor production at low cost is one of the essential characteristics of point-source resources. Besides making agriculture spatially concentrated, irrigation also eases monitoring by making production more transparent. As pointed out by Mayshar *et al.* (2012),

[12] Fisher (1928).
[13] See, *e.g.*, Ostrom and Gardner (1993), footnote 15.

the observability of the amount of water allocated to the individual plot in irrigated areas increases the predictability of yields. This made absentee landlordism based on sharecropping or serfdom more attractive. The land owner did not need to monitor effort directly. Shirking could be prevented by promising severe punishment if the tenant or serf failed to produce the amount of crops predicted by the amount of water allocated to the plots. Large land holdings were therefore more economically attractive in irrigated societies than in rainfed areas and, as a consequence, a centralization of land ownership in the hands of an elite or a despotic state were more likely to occur. The tendency was reinforced by the high fixed costs of building and maintaining irrigation systems as explained by Commodore B. Fisher in the quote above.

Transparency of agricultural production also facilitated taxation. In Egypt, for example, accurate estimates of yields could be calculated in advance by observing the height reached by the annual floods, and taxes could be set accordingly.[14] Ease of taxation reduced the bargaining power of the population when the rulers were in need of revenue which, as argued by Bates and Lien (1985), made the rulers less likely to offer representation in return for tax payments.

2.3 Historical examples

Serfdom and sharecropping seem to have been the norm in the ancient societies that Wittfogel (1957) identified as hydraulic. An interesting case analyzed by Mayshar *et al.* (2012) is Mesopotamia. Agriculture in Lower Mesopotamia (Babylonia) was fed by water from Tigris and Euphrates, and land ownership was concentrated within a small, but powerful elite. Independent owner-occupied farms were, by contrast, prevalent in Upper Mesopotamia where agriculture was chiefly rainfed. A more recent example is documented by Islam (1997), who show that the correlation between the share of land with canal irrigation and the share of land tilled by tenants was 0.58 across districts in Punjab in the early 1920s.

Egypt and Mesopotamia are the classic examples of ancient irrigation civilizations. In addition, Wittfogel (1957) mentions China, the Mayas, the Incas, the Pueblos (Mexico/United States), and the Chagga (Tanzania).

[14] Cooper (1976) documents this procedure. See also Mayshar *et al.* (2012).

A notable, but less well known, example is a society existing from around 900-1532 AD in the Pampa de Chaparrí on the north coast of Peru.[15] The society was governed by a hierarchical system of lords, each of whom distributed the water on his/her land to the local farmers in return for labor. In return for water rights, each lord paid a tribute to another lord above him. In effect, the society was organized in a pyramid-shaped hierarchy with a centralized government at the pinnacle. Thus, the state managed to extract considerable rents even though it did not control the distribution of water in detail. Moreover, the archaeological evidence presented by Hayashida (2006) indicates that these hierarchical institutions survived the rule of three different civilizations (Sicán, Chimú, and Inka).

Another example is the princely state of Hunza in Pakistan, established by Mir Silim Khan in 1790.[16] In earlier periods, the region was split in three smaller city states governed by a Mir, who mostly held nominal power. That changed when Silim Khan came to power. He ordered the construction of massive irrigation systems and united the Hunza in one state. This enabled him to control the allocation of water to each Hunza community and coordinate agricultural activities in detail. Villagers were presented with an agricultural timetable stating when to plant, irrigate, and harvest their crops. Farmers who failed to follow these directions were fined. The irrigation system generated large amounts of revenue for the Mir, who exercised considerable political power through a hierarchy of officials.

2.4 Existing institutions

Point-source resource abundance does not always lead to a resource curse. It seems to depend on the quality of the institutions present in a country or region when the resource is discovered or becomes feasible to extract.[17] Oil discoveries in the North Sea have not turned Norway into an authoritarian country, just as oil discoveries in Texas and the Mexican gulf have had little impact on institutions in the United States. Norway and the United States both possessed well developed and solid democratic institutions when oil was discovered. They had a diversified economy, with other groups providing democratic opposition to the special interest groups of

[15] See Hayashida (2006) for further discusson of Pampa de Chaparrí.
[16] See Sidky (1997).
[17] See, *e.g.*, Boschini *et al.* (2007) and Mehlum *et al.* (2006).

the oil industry. In poorer countries, where democratic institutions are fragile or non-existent, ruling elites are in a better position to shape and use institutions to turn such oil bonanzas into their personal cash cows. The resulting financial gain can then be used to entrench their power further. Many of the OPEC member states in the Persian Gulf fit this pattern.[18]

Irrigation is an old technology, mastered already in ancient Mesopotamia. Strong democratic institutions found in Western democracies are new in comparison. Few places had institutions present providing checks and balances on the ruling elite when irrigation was first introduced. The dramatic increase in the extent of irrigation in the 20$^{\text{th}}$ century, however, is unlikely to have had any detrimental effect on institutional quality in Western democracies.

2.5 Institutional persistence

Institutions are sustained by more than habit. They often accommodate narrow special interest groups who will fight to keep their privileges. Both the elite and the institutions of irrigation-based societies may therefore survive, even if agriculture ceases to be an important part of the economy.

There are numerous examples of such institutional persistence. Following the pioneering work of Acemoglu *et al.* (2001), many studies use the transplantation of institutions during the colonial era as random experiments to identify the effect on present-day institutions. Dell (2010) shows that the mining mita in Peru, a system of coerced labor abolished in 1812, still exerts a negative effect on land tenure and public goods provision in the affected areas. Iyer and Banerjee (2005) and Iyer (2010) use regional variation in the colonial institutions set up by the British in India and show that it still matters today. And a wide range of studies use cross-country evidence to establish the importance of colonial institutions on present-day outcomes.[19]

Engerman and Sokoloff (2000) argue that even when slavery was abolished in the Americas, the plantation-owning elites maintained their land ownership and much of their political power.[20] Democracy would disturb this position of power, and the elites consequently sup-

[18] See Ross (2001), Ross (2012).

[19] *E.g.*, Feyrer and Sacerdote (2009), Olsson (2009), and Hariri (2012).

[20] See also Isham *et al.* (2005) for a discussion.

ported autocratic regimes. Even within the United States, slavery had a lasting legacy on institutions. Lagerlöf (2004) and Soares *et al.* (2012) show that present-day variation in institutional quality and income inequality within the United States can be traced to antebellum slavery.

Inspired by the insights of Sokoloff and Engerman, Easterly (2007) use the suitability for sugar cane relative to wheat as an instrument for present-day inequality. Instrumented inequality, in turn, predicts poor institutional outcomes and economic underdevelopment. It also predicts less schooling, consistent with the model and the results reported by Galor *et al.* (2009).

The argument in this paper is similar to the argument made by Engerman and Sokoloff (2000) and Easterly (2007). The elites in control of the irrigation systems were able to amass large personal fortunes and political power. Irrigation also barred the entry of independent farmers, and thus slowed the emergence of a middle class. Both developments made it easier for the ruling elite to fend off calls for democracy.

3 Methodology and irrigation data

The arguments outlined above lead to the testable implication that societies with a history of irrigation are more autocratic today. To test this, we would like to estimate a regression on the form:

$$institutions_i = \alpha_0 + \alpha_1 irrigation_i + X_i'\beta + u_i \ , \tag{1}$$

where i indexes the unit of observation, *institutions* is a measure of autocracy, *irrigation* is a measure of actual historical irrigation, X is a vector of control variables, and u is an error term. This specification, however, leads to multiple problems.

First of all, irrigation is likely to be endogenous. Higher income could lead to more investments in irrigation projects. If democratic institutions are conducive to economic development, this would bias the estimate of α_1. Alternatively, strong autocratic regimes may be better at constructing large irrigation works.[21]

[21] This has often been used to criticize Wittfogel (1957), see, *e.g.*, Fukuyama (2011).

Another issue is the lack of historical irrigation data at the cross-country level. Systematic surveys of irrigated areas began only in 1961, when the Food and Agriculture Organization (FAO) started to collect data.[22] Reduced costs and new technologies, though, have caused a fivefold increase in the area equipped for irrigation in the 20$^{\text{th}}$ century and modern data is therefore hardly a good proxy for historical irrigation.[23]

Furthermore, it is not clear that modern irrigation technologies are associated with the same point-source resource qualities as traditional irrigation methods. Traditional irrigation relied on an observable water source and costly infrastructure, whereas modern drilling and pumping technologies have allowed independent farmers to reach aquifers deep beneath the surface at low costs. Technological and economic progress may therefore have weakened the contemporaneous link between irrigation and institutional quality.[24] The low cost of irrigation today also means that many areas are equipped for irrigation, even if irrigation only increases yields marginally. Moreover, in many areas in Europe and the United States, modern irrigation systems are just a precautionary measure and only used when an occasional draught hits.[25] Without a substantial effect on annual yields, irrigation is unlikely to have a substantial effect on institutions.

3.1 Irrigation impact and irrigation potential

To avoid biases due to endogeneity, and as an alternative to lacking historical data, we use a measure of the potential for irrigation which is based on geographical and climatic factors. As a benchmark, this measure is our main explanatory variable. We also run IV regressions where actual irrigation is instrumented with irrigation potential. However, since the data on land equipped for irrigation across countries and across subnational regions is a noisy measure of historical irrigation use, the first stage becomes weak. In the sample of ethnographic societies,

[22] Data do exist on estimates of land equipped for irrigation for earlier years, which we elaborate on further below and also use for robustness checks.

[23] Freydank and Siebert (2008).

[24] The Aquastat database has some information on the type of irrigation used, but only for a small sample of countries where irrigation is widely used. The lack of a control group of countries makes the data unsuitable for our analysis.

[25] Freydank and Siebert (2008).

we have a more reliable measure of historical irrigation and hence the first stage is strong. To avoid the problem of weak identification, we use the reduced form as our main specification, and run IV regressions as robustness checks.

Our irrigation potential variable is based on data from the Food and Agriculture Organization (FAO)'s global Agro-Ecological Zones (GAEZ) 2002 database.[26] Using geographical and climatic variables such as soil fertility, precipitation, sunlight hours, and temperature, FAO computes how much the annual agricultural yield can be expected to increase when an area is irrigated compared to the yield obtained without irrigation (i.e., under completely rainfed conditions). Only areas where irrigation is technically feasible are considered, that is, areas close to a water source. The calculation is done for each 0.083x0.083^o (latitude-by-longitude) grid cell, which corresponds to 9x9 km at the Equator.

The FAO divides the potential gain from irrigation into five impact classes. Impact class 1 indicates areas where rainfall is sufficient and where additional water will not increase yields (light grey in the map in Figure 1). Impact class 2 is areas where irrigation potentially can increase yields by 1-20 percent. Impact class 3 is 20-50 percent, impact class 4 is 50-100 percent, and impact class 5 is more than 100 percent. Impact class 5 is usually found in areas where irrigation permits multiple harvests or where no agriculture is possible without irrigation. The geographical distribution of the five impact classes is shown in Figure 1. Areas which are too dry to admit rainfed agriculture and which do not have a nearby water source are classified as unsuitable to agriculture (dark grey areas in the map).

We define *irrigation potential* as the area of land in impact class 5 as a fraction of arable land:

$$irrigation\ potential = \frac{impact\ class\ 5}{arable\ land}. \tag{2}$$

Arable land is land that is potentially suitable for agriculture if water is available. That excludes areas where the terrain is too rugged, the climate is too cold, and the soil too sandy to grow crops, but uncleared forest is included. Arable land enters the denominator as we are interested in institutional quality in irrigation dependent areas relative to rainfed areas.

[26]Our empirical strategy is similar to that of Nunn and Qian (2011), who use agricultural suitability for growing potatoes as a source of exogenous variation in actual potato cultivation.

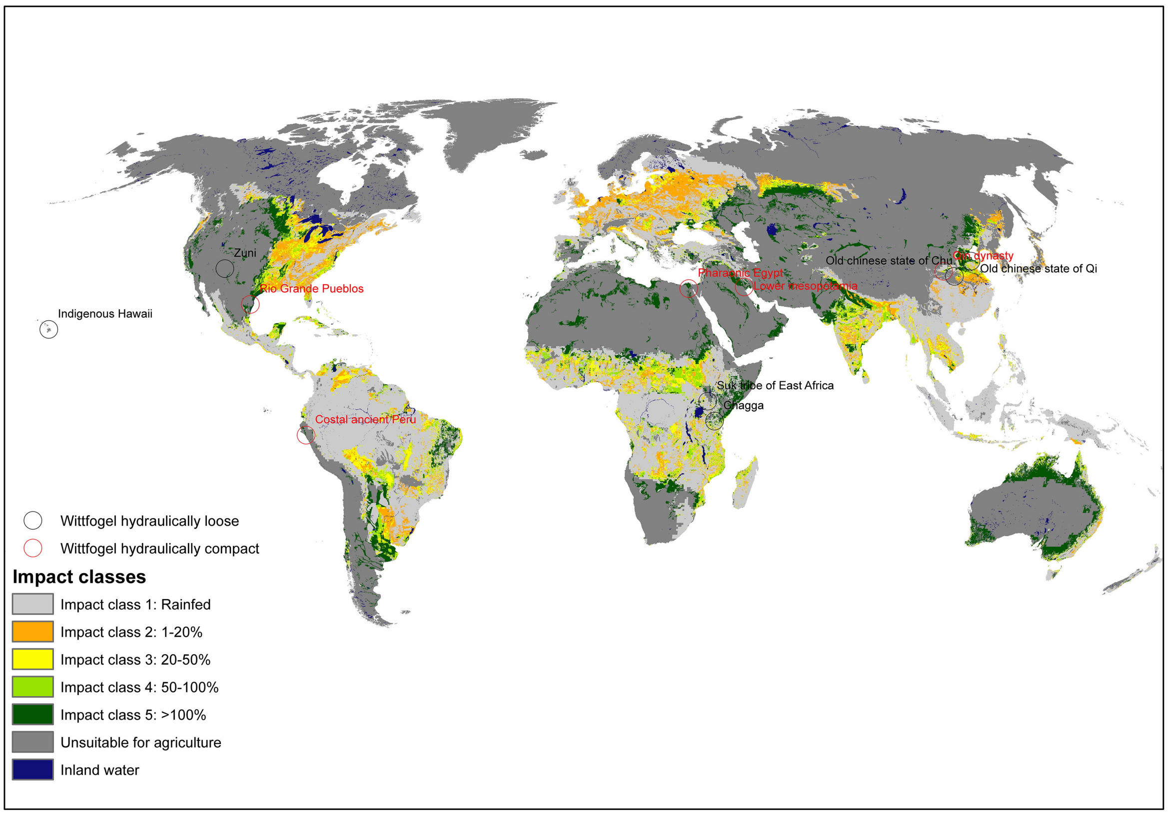

Figure 1: Irrigation impact classes.
Sources: Impact classes: Food and Agriculture Organization (FAO)'s global Agro-Ecological Zones (GAEZ) 2002 database, hydraulic societies: Wittfogel (1957).

Moreover, Malthusian dynamics have ensured that population densities are relatively low in most areas unsuitable for agriculture. The dominating institutions in an area are likely to have evolved in the areas that hold the greatest number of people, and, by focusing on arable land only, we get a clearer picture of the circumstances that shaped them in areas. Dividing by total land instead would introduce a measurement error. The vast deserts of Egypt would, for example, make the country seem less irrigation dependent that it is actually the case.

We define arable land as land belonging to either of the 5 impact classes, and *irrigation potential* consequently ranges from 0 to 1. Examples of countries with *irrigation potential* $= 1$ are Egypt, Turkmenistan, and Qatar. Examples of countries with irrigation potential $= 0$ are United Kingdom, Denmark, and Macedonia.[27] Countries with intermediate levels of irrigation potential include Argentine (0.42), Jordan (0.54), and Namibia (0.56).

We disregard impact classes below impact class 5 for two reasons. First, as we will show in the next subsection, irrigation potential based on impact class 5 is a better predictor of actual historical irrigation than a measure that includes one or more of the lower impact classes. Second, as explained above, mechanization and development of new types of irrigation (*e.g.*, sprinkler irrigation) has reduced costs. At the same time, the development of new types of seed, fertilizer, and pesticides has made the *absolute* gain from irrigation larger in each impact class, in effect reducing the relative cost of constructing irrigation systems even further. While it is profitable to adopt irrigation in many areas with impact class 2 or 3 today, it was probably neither feasible nor profitable historically. And historical irrigation is what matters for our hypothesis.

3.2 Irrigation potential and actual irrigation

In addition to the irrigation impact classes, Figure 1 also shows the location of the societies which Wittfogel (1957) identified as hydraulic, *i.e.*, autocratic societies dependent on irrigation

[27] These countries would have a much higher irrigation potential if we used the lowest cut-off level of >0%, which is in line with the relatively high present day irrigation levels in these countries. This supports the idea that present day costs related to irrigation are fairly low, meaning that a lower benefit is needed in order for irrigation agriculture to be profitable.

works on a large scale.[28] Most of these societies are located in areas with irrigation impact class 5, indicating that our irrigation potential variable is capturing some dimension of historical irrigation. To validate our measure of irrigation potential systematically, we now compare it to three data sets with information on actual irrigation.

The Ethnographic Atlas compiled by Murdock (1967) contains historical information on 1167 societies surveyed by ethnographers. The societies are scattered across the globe and measured at a point in time before contact with Europeans. The societies were observed at different points in time, ranging from 1750 BC to 1965 AD. Most of them, however, were observed in the 19th and early 20th century. 312 of the societies in the Atlas had intensive agriculture at the time of observation. Of these, 126 had irrigated intensive agriculture.[29] Coordinates provided in the Atlas allow us to merge the ethnographic data with our measure of irrigation potential and other geographical variables.[30]

Freydank and Siebert (2008) have compiled a comprehensive data set on land equipped for irrigation in 236 countries. The data covers 1900 to 2003, and is based on numerous sources. However, data before 1961 when FAO started to collect irrigation data are mainly estimates based on extrapolation, comparisons with other countries, and qualitative information. Less than 15 percent of the observations in 1900 are based on actual data compared to 95 percent of the observations in 2000.

Siebert *et al.* (2007) provide a disaggregated map of land equipped for irrigation in 2000. The level of disaggregation is 0.083x0.083^o, corresponding to the level of disaggregation in our irrigation potential data shown in Figure 1.

Table 1 shows the simple correlations between actual irrigation according to the three data sets, and four measures of irrigation potential. Our baseline measure, based on impact class 5, is in the top row (measures share of arable land where irrigation can more than double agricultural yields). Irrigation potential (IC 4-5) in the second row includes impact class 4 and

[28] Also marked on the map is whether Wittfogel identified the societies as loose or compact hydraulic societies. While both types are hydraulic, the latter were somewhat more hydraulic than the former.

[29] Seven additional societies with irrigation are placed on small islands where no irrigation potential data is available. They are left out of the analysis.

[30] We follow Alesina *et al.* (2013) and calculate the geographic variables for the area within a 200 km radius from the coordinates given in the Ethnographic Atlas.

5 (irrigation can increase yields by at least 50%). Irrigation potential (IC 3-5) includes impact class 3, 4 and 5 and so on.

The coefficient of correlation is positive and significant at a 1-percent level, no matter what irrigation data and which irrigation potential measure we use. But our preferred measure using only impact class 5 has the highest correlation with actual historical irrigation use. The correlations with historical irrigation fall gradually as more impact classes are added to the irrigation potential variable. This is consistent with our expectation that a large potential yield increase was necessary in order for historical societies to be willing to incur the high costs of engaging in irrigation.

Table 1. Correlations between actual and potential irrigation

	Actual historical irrigation[a]	Irrigation 1900 (estimate)[b]	Irrigation 2000 (actual)[b]	Irrigation 2000 (actual)[c]
Unit	Ethnographic society	Country	Country	0.083x0.083^{o} grid
Irrigation potential (IC 5)	0.314***	0.344***	0.285***	0.134***
Irrigation potential (IC 4-5)	0.298***	0.343***	0.272***	0.148***
Irrigation potential (IC 3-5)	0.272***	0.292***	0.239***	0.147***
Irrigation potential (IC 2-5)	0.208***	0.241***	0.205***	0.153***
Observations	312	192	192	841,119

Notes: Actual irrigation in the ethnographic societies is a dummy variable = 1 if agriculture is irrigation-based and 0 if it is rainfed (column 1), while across countries and grid cells (columns 2-4) it measures land equipped for irrigation as a share of total arable land. Irrigation potential (IC 5) is the fraction of arable land where irrigation can more than double agricultural yields, for irrigation potential (IC 4-5), irrigation can increase yields by at least 50%, for irrigation potential (3-5) irrigation can increase yields by at least 20%, and last for irrigation potential (IC 2-5), irrigation can increase yields by at least 1%. ***, **, and * indicate significance at the 1, 5, and 10% level, respectively. [a]Source: Murdock (1967). [b]Source: Freydank and Siebert (2008). [c]Source: Siebert *et al.* (2007).

4 Empirical results at the country level

Institutional quality is hard to measure, and no quantitative yard stick for democracy is perfect. The most widely used indicator in quantitative studies of democracy is the *polity*2 index from the Marshall *et al.* (2010) Polity IV database.[31] It is composed of two subindices: The democracy subindex reflects constitutional constraints on the executive and the ability of the population to elect leaders, vote for policies, and participate in the political process. The autocracy subindex reflects the lack of constraints on the executive and the degree to which the executive can control political participation and select new leaders. Each of these indices ranges from 0 to 10. The *polity*2 index is computed as the democracy subindex subtracted by the autocracy subindex, and thus ranges from -10 to 10 (high values meaning more democratic).

Examples of countries with a score of 10 in the *polity*2 index is the United States, United Kingdom, and Sweden. The only countries to score a -10 are Saudi Arabia and Oman, but Swaziland, North Korea, and Uzbekistan come close with a *polity*2 score of -9 or less. In the midrange, we find a number of Sub-Saharan African countries along with countries such as Kyrgyzstan, Haiti, and Cambodia.

Column (1) in Table 2 shows the relation between *irrigation potential* and the *polity*2 index in 2010. The coefficient from a simple OLS regression is negative and significant, indicating that countries with higher irrigation potential are more autocratic.[32] Taken at face value, the estimate implies that a region with no irrigation potential will be 9.5 points more democratic on the 21 point *polity*2 scale than a country with full irrigation potential.

We are interested in long-term effects, and using a single year of observation may therefore introduce noise in the *polity*2 scores in countries with unstable regimes. We therefore follow Hariri (2012) and use the average of the *polity*2 index over the post-Cold War period (1991-2010) as our main outcome variable in the empirical analysis below. As shown in column (2) of Table 2, the estimated coefficient is indistinguishable from the single year 2010.

Columns (3)-(6) illustrate that the link between irrigation and autocracy is no new phe-

[31] The data is available online from www.systemicpeace.org/polity/polity4.htm.

[32] The effect goes through both subindices of the *polity*2 index. The coefficient on irrigation potential in a regression with the democracy index substituted for the *polity*2 index is -5.207. The similar coefficient for the autocracy subindex is 4.886. Both estimates are significant at the 1% level.

nomenon. While the estimate on irrigation is somewhat lower and the standard errors are larger due to smaller samples, it is still significant in all four half-centuries between 1800 and 2000.

Table 2. Various measures of democracy on irrigation potential

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Dependent variable	polity2	polity2	polity2	polity2	polity2	polity2	fh_avg
Irrigation potential (%)	-9.558***	-9.726***	-8.537***	-5.917**	-6.150***	-3.887*	2.599***
	(1.497)	(1.386)	(1.130)	(2.282)	(2.183)	(2.036)	(0.393)
Observations	158	160	160	77	50	44	177
R-squared	0.216	0.227	0.187	0.069	0.057	0.030	0.155
Period	2010	1991-2010	1950-2010	1900-1950	1850-1900	1800-1850	1991-2010

Notes: OLS estimates. The dependent variable in columns (1)-(6) is averages of the polity2 index. It measures how democratic political institutions are and ranges from -10 (least democratic) to 10 (most democratic). The dependent variable in column (1) is computed in 2010, in column (2) is an average over the period 1991-2010, while columns (2)-(6) use different subperiods of that. The dependent variable in column (7) is an average of civil liberties (ranges 1-7) and political rights (ranges 1-7) from Freedom House, where a higher score indicates a lower degree of freedom. Irrigation potential ranges from 0 to 1 and measures the fraction of arable land where irrigation can more than double agricultural yields compared to rainfed agriculture. ***, **, and * indicate significance at the 1, 5, and 10% level, respectively. All regressions include a constant. Robust standard errors in parentheses.

In column (7), an alternative measure of democracy is used: The average of the Civil Liberties and Political Rights ratings by Freedom House.[33,34] Countries are categorized on a scale from 1 to 7 according to the amount of political rights and civil liberties they offer their citizens. A rating of 1 indicates the highest degree of freedom and 7 indicates the lowest. As expected, citizens living in areas with higher irrigation potential are less likely to enjoy civil liberties and political rights. In the remainder of this paper, we use the *polity*2 index as explanatory variable, but we obtain similar results using the Freedom House measure.

4.1 Geographical control variables

Table 3, column (1) restates the simple relation between the *polity*2 index averaged over the period 1991-2010 and irrigation potential. In column (2), continent dummies (Europe, Asia, North America, South America, Africa, and Oceania) are included in the regression.

[33] Available online at www.freedomhouse.org.

[34] In an earlier version of the paper, we used the less popular "freedom indicator" from Freedom House and obtained similar results.

The estimate of interest decreases because Africa and Asia have significantly higher irrigation potential and, at the same time, are more autocratic than the average country. Ever since it was suggested by Hall and Jones (1999), the distance from the Equator has been widely used as a proxy for development or institutional quality. As shown in column (3), countries located further away from the Equator are indeed more democratic, but the coefficient on irrigation potential is unchanged and still highly significant.

Table 3. Democracy on irrigation potential controlling for geography

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Irrigation potential (%)	-9.726***	-5.786***	-6.546***	-6.320***	-5.697***	-5.990***	-5.318**		-6.732**
	(1.386)	(1.543)	(1.564)	(2.148)	(1.497)	(1.486)	(2.553)		(2.826)
Absolute latitude			0.071**				0.101		
			(0.033)				(0.066)		
Precipitation				-0.378			1.223	5.785**	-1.270
				(0.898)			(1.158)	(2.323)	(3.493)
Temperature					-0.097		0.010		
					(0.067)		(0.125)		
Soil constraints (%)						-5.941	-4.896		
						(4.963)	(4.804)		
Squared precipitation								-1.796*	0.336
								(0.935)	(1.208)
Observations	160	160	160	160	160	160	160	160	160
R-squared	0.227	0.480	0.493	0.481	0.489	0.485	0.500	0.452	0.481
Continent dummies	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: OLS estimates. The dependent variable is the polity2 index which ranges from -10 (least democratic) to 10 (most democratic). Irrigation potential ranges from 0 to 1 and measures the fraction of arable land where irrigation can more than double agricultural yields compared to rainfed agriculture. All geographical variables are computed by averaging over the modern-day borders of the country. Temperature is average daily temperature over the period 1961-1990 in degrees Celsius. Precipitation is the average daily precipitation over the period 1961-1990 in meters. Soil constraints is the fraction of land with more than few soil and terrain constraints to crop growth. ***, **, and * indicate significance at the 1, 5, and 10% level, respectively. All regressions include a constant. Robust standard errors in parentheses.

Irrigation potential is based on numerous geographical and climatic variables. To check whether it is one of the components of irrigation potential variable (e.g., precipitation), and not the variable itself, that is correlated with the *polity*2 index, we include other potentially relevant geographical variables in our regression. [35] We control for each of these factors one by one in columns (4)-(6) and simultaneously in column (7). None of these are individually

[35] Temperature, precipitation, and soil constraints are from FAO's Agro-Ecological Zones Database. Precipitation and temperature are averaged over the period 1961-1990. Soil quality is the combination of soil depth, fertility, drainage, texture, chemical,a dn terrain slope constraints. Specifically, the measure is the share of land which ranges between being unsuitable for agriculture to having few soil constraints. The omitted categories are no or very few soil constraints.

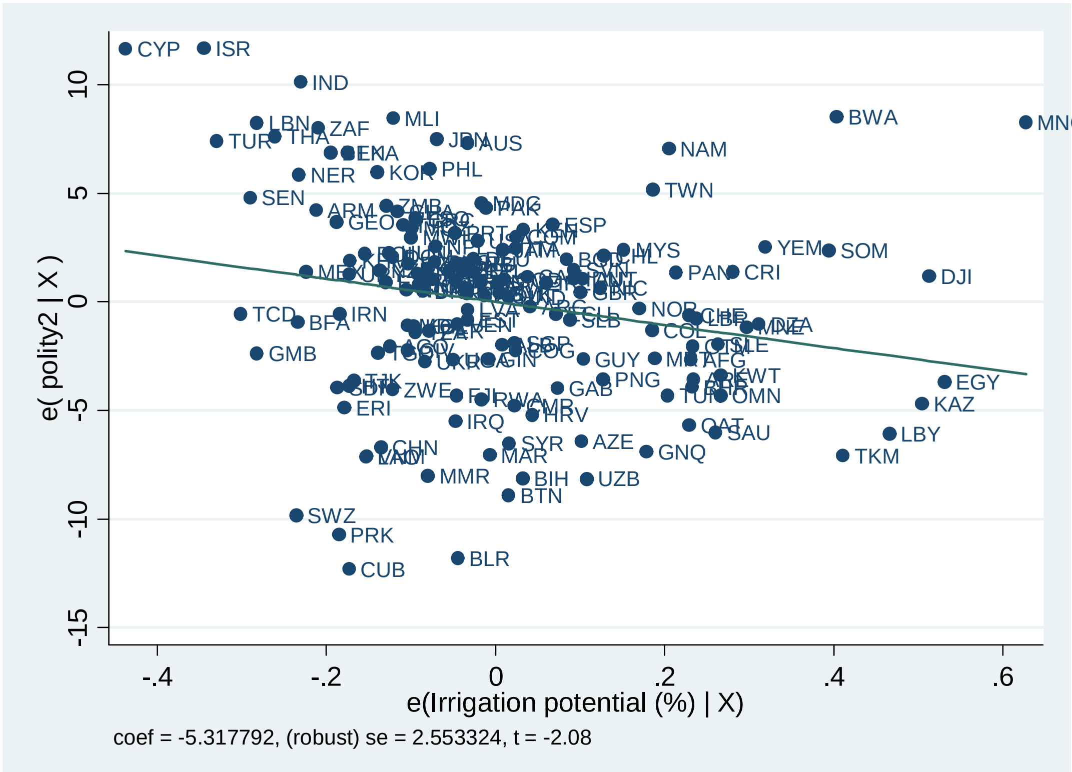

Figure 2: AV-plot illustrating the partial effect of irrigation potential on polity2. The specification corresponds to column (7) of Table 3.

significant, and their inclusion has negligible impact on the irrigation potential coefficient. The added-variable plot of column (7) of Table 3 shown in Figure 2 confirms visually that our finding is not driven by a particular country or group of countries.[36]

Haber and Menaldo (2010) show that precipitation exerts a non-linear effect on political institutions with intermediate levels of rainfall being the most conducive to democracy. They argue that this relationship is a proxy for the climatic suitability for growing cereals, a class of crops which are storable with only modest returns to scale in production. Storability allows for an accumulation of surplus which, according to Haber and Menaldo (2010), historically has permitted trade and specialization. Modest scale returns created a more equal distribution of property, an argument closely related to ours. Combined, Haber and Menaldo (2010) contend that these characteristics of cereal production gave rise to stronger property rights, human

[36] The result also holds if we exclude the 10 countries with *irrigation potential* $= 1$, the 44 countries with *irrigation potential* $= 0$, or all 54 countries at the same time. If anything, the level of significance and the estimate rise in absolute value.

capital investments, and the development of representative institutions.

In our regressions, we capture the nonlinear relationship between rainfall and democracy by adding precipitation and precipitation squared as control variables in Table 3. Column (8) shows that the nonlinear relationship exists when irrigation potential is excluded from the regression. However, when we include irrigation potential in column (9), both rainfall terms become insignificant, individually and jointly.[37]

The coefficient on *irrigation potential* is 5-6 in most of the specifications in Table 3 indicating that going from no irrigation potential to full irrigation potential will move a country 5-6 points toward democracy on the *polity*2 scale. Or, to give an example, Algeria as of 2010 ($polity2 = 2, irrigation\ potential = 0.79$) would be as democratic as Turkey ($polity2 = 7, irrigation\ potential = 0.08$) if it did not have a history of irrigation.

A range of other geographical control variables suggested in the literature to influence economic development or institutions were also tested. These include: malaria ecology, distance to coast or navigable river, land within tropics, terrain ruggedness, total area, a dummy for whether a country is landlocked or not, a measure of the standard deviation of rain, and arable land as a share of total area. Adding these variables does not change the estimated coefficient on irrigation potential. The results are reported in Appendix Table A1.

4.2 Natural resource abundance

If irrigation potential is correlated with the presence of other point-source resources that are not sufficiently accounted for in the regressions, our estimates may be biased. One obvious worry is that the areas suitable for irrigation are also suitable for plantation crops. To check whether this biases our results, we include the proxy for plantation crop suitability suggested by Easterly (2007) in the regression. As shown in Column (2) of Table 4, it is insignificant, and the coefficient on irrigation potential is unchanged.[38]

The traditional examples of cursed point-source resources are fossil fuels and minerals. In columns (3)-(5) of table 4, we include three measures of such resources found in the literature. Only oil production is significant. Including oil production also reduces the estimated coefficient on irrigation potential, presumably because a number of the oil producing Middle Eastern

[37] Confirmed by an F-test with a p-value of 0.897.

[38] We have more observations than Easterly (2007) as we constructed the wheat-to-sugar measure using grid level data from the Global Agro-Ecological Zones Database, available online at http://www.fao.org/nr/gaez/en/. It is the inclusion of continents, not irrigation potential, that renders the estimate of the wheat-sugar relation insignificant.

countries have high irrigation potential.

All resource control variables are included simultaneously in Column (6). The main result pertains: Countries with higher irrigation potential are more autocratic.

Table 4. Democracy on irrigation potential controlling for resources

	(1)	(2)	(3)	(4)	(5)	(6)
Irrigation potential (%)	-6.404***	-6.597***	-5.060***	-6.509***	-6.376***	-5.371***
	(1.584)	(1.580)	(1.704)	(1.526)	(1.574)	(1.658)
(log) Total area with wheat / sugar		3.641				2.352
		(2.284)				(2.391)
Oil (1000 barrels/day/cap)			-5.521***			-4.909***
			(1.842)			(1.794)
Mineral rents, % of GDP				0.066		0.036
				(0.128)		(0.118)
Diamond dummy					1.178	0.837
					(1.507)	(1.514)
Observations	152	152	152	152	152	152
R-squared	0.491	0.498	0.510	0.492	0.494	0.516
Continent dummies	Yes	Yes	Yes	Yes	Yes	Yes

Notes: OLS estimates. The dependent variable is the polity2 index which ranges from -10 (least democratic) to 10 (most democratic). Irrigation potential ranges from 0 to 1 and measures the fraction of arable land where irrigation can more than double agricultural yields compared to rainfed agriculture. ***, **, and * indicate significance at the 1, 5, and 10% level, respectively. All regressions include a constant. Robust standard errors in parentheses.

4.3 Development and colonization

Lipset (1959) famously hypothesized that democracy is a consequence of economic modernization. If the theory is correct and if irrigation is correlated with economic development, the observed effect of irrigation on institutional quality could work through modernization. For instance, a high irrigation potential could slow democratization if irrigated societies specialized in agricultural production and failed to develop modern industries.[39]

As a first step to check whether that is the case, column (2) of Table 5 includes (the logarithm of) real GDP per capita in year 2000 from Penn World Tables. As expected, richer countries are more democratic. But the effect does not seem to work through irrigation, since the estimated coefficient on irrigation potential is unchanged. Note, however, that including GDP could lead to an estimation bias due to endogeneity.

In column (3) and (4), we include, respectively, the number of years since the Neolithic transition, which measures the number of years since the transition from hunting and gathering

[39] Matsuyama (1992), Galor and Mountford (2006, 2008), and Williamson (2011), among others, argue that such specialization in agricultural production might explain the unequal global distribution of income today.

to agriculture, and the State Antiquity Index, which captures the cumulated number of years a state has been present within modern-day country borders.[40] Both measures have been shown to be correlated to contemporary as well as historical measures of economic development.[41] As shown in columns (3) and (4), the coefficients on both variables are insignificant.

Column (5) includes population density in 1500 AD from MacEvedy and Jones (1978). Population density is a standard measure of economic development in Malthusian economies where higher living standards translated into higher fertility and/or lower mortality (see e.g., Ashraf and Galor (2011)). In support of Lipset (1959), the coefficient on population density is positive, indicating that areas which were more developed historically are more democratic today. At first, this result seems at odds with the reversal-of-fortune argument put forward by Acemoglu *et al.* (2002). They argue that densely populated regions colonized by European powers received fewer European settlers bringing democratic institutions with them from their home country. However, the estimated coefficient on population density is mainly driven by Europe and countries that were never colonized by Europeans.

Table 5. Democracy on irrigation potential controlling for development and colonization

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Irrigation potential (%)	-5.672***	-6.344***	-4.798**	-5.723***	-4.831***	-5.680***	-5.750***	-5.839***	-4.128*	-5.627**
	(1.855)	(1.985)	(2.214)	(2.009)	(1.819)	(1.820)	(1.858)	(1.862)	(2.389)	(2.238)
(log) Real GDP/cap, 2000		1.095**							0.759	0.521
		(0.442)							(0.478)	(0.445)
Years since Neolithic			-0.406						-0.488	-0.531
			(0.382)						(0.381)	(0.374)
State Antiquity Index				0.000					-0.001	
				(0.001)					(0.001)	
Pop density, 1500					0.137***				0.146***	0.142***
					(0.044)				(0.053)	(0.050)
Colony dummy						-0.043			-0.863	-2.088
						(1.691)			(1.663)	(1.524)
European language (%)							2.874***		0.752	0.958
							(0.890)		(0.872)	(0.916)
European descendants (%)								2.911***	0.234	0.385
								(0.997)	(1.072)	(1.105)
Observations	139	139	139	139	139	139	139	139	139	148
R-squared	0.472	0.502	0.481	0.473	0.502	0.472	0.485	0.484	0.538	0.559
Continent dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: OLS estimates. The dependent variable is the polity2 index which ranges from -10 (least democratic) to 10 (most democratic). Irrigation potential ranges from 0 to 1 and measures the fraction of arable land where

[40] These variables are obtained from, respectively, Putterman and Trainor (2006), and Bocksette and Putterman (2007). Using the Putterman (2008) migration-adjusted years since the Neolithic Revolution produces similar results as the ones reported in Table 5.

[41] *E.g.*, Diamond (1997), Bockstette *et al.* (2002), Hibbs and Olsson (2004) and Hariri (2012). Olsson and Paik (2013) also suggest that within Europe, North Africa, and the Middle East, an early agricultural transition is associated with autocratic institutions today.

irrigation can more than double agricultural yields compared to rainfed agriculture. Years since Neolithic measures the years passed since agriculture was first introduced in a society within the modern-day borders of the country. The State Antiquity Index is a cumulative measure of how many years the country or any society within the country has been governed by a centralized state. Population density, 1500 is the population in year 1500 as a share of total area. log real GDP per capita is measured in PPP in 2000. The colony dummy equals 1 if the country was ever colonized and 0 otherwise. ***, **, and * indicate significance at the 1, 5, and 10% level, respectively. All regressions include a constant. Robust standard errors in parentheses.

A growing body of research documents the importance of colonization for current institutions.[42] If irrigation potential is correlated with colonization, our estimate of interest might be biased. Column (6) of Table 5 includes a dummy equal to one if the country was ever colonized. Colonization does not appear to explain variation in present-day democracy in addition to the variation explained by irrigation potential. Columns (7) and (8) include measures of the extent of European influence: the fraction of the population that speaks a European language and the fraction of the population with European descendants (descendants from Belgium, Germany, Spain, United Kingdom, Italy, Netherlands, France, and Portugal). The impact of irrigation potential is unaltered.

All variables are included simultaneously in Column (9). The estimate of interest is reduced somewhat compared to column (1), albeit not significantly. The State Antiquity Index has fewer observations than the other variables. It is also insignificant, and we therefore exclude it in column (10) to increase the number of observations. As a result, both the size and the significance of the irrigation potential coefficient increases.

We now turn to a more thorough investigation of whether the link between irrigation and autocracy is caused by colonization. Table 6 splits the sample in two: a sample of the 64 countries that were never a colony (columns 1-2) and a sample of the 96 countries that were colonized at some point in time (columns 3-5).

Table 6 shows that the coefficient on irrigation potential retains its sign and significance in both subsamples. However, the impact and explanatory power of irrigation is stronger in the sample of countries that were never a colony. One interpretation of this finding is that European colonialism diluted the effect of irrigation. This would be consistent the large literature arguing that colonization shaped institutions.

[42] *E.g.*, Acemoglu *et al.* (2001, 2002), Engerman and Sokoloff (2000), Iyer and Banerjee (2005), Nunn (2007), Feyrer and Sacerdote (2009), Olsson (2009), Dell (2010), and Hariri (2012).

Table 6. Democracy on irrigation potential in non-colonies vs colonies

	(1)	(2)	(3)	(4)	(5)
Sample	Non-colonies		Former colonies		
Irrigation potential (%)	-15.436***	-11.364***	-6.051***	-3.441**	-3.352*
	(2.859)	(3.549)	(1.576)	(1.508)	(1.716)
Malaria ecology index					0.012
					(0.080)
Observations	64	64	96	96	96
R-squared	0.485	0.560	0.109	0.423	0.423
Continent dummies	No	Yes	No	Yes	Yes

Notes: OLS estimates. The dependent variable is the polity2 index which ranges from -10 (least democratic) to 10 (most democratic). Irrigation potential ranges from 0 to 1 and measures the fraction of arable land where irrigation can more than double agricultural yields compared to rainfed agriculture. Columns (1) and (2) include only countries that were never colonized, while columns (3)-(5) include only countries that were once a colony. Malaria ecology measures the contribution of vectors to the force of malaria transmission. ***, **, and * indicate significance at the 1, 5, and 10% level, respectively. All regressions include a constant. Robust standard errors in parentheses.

In the last column of Table 6, we include malaria ecology in order to test the notion that the disease environment was crucial for the institutions set up by the colonial powers.[43] We do not find evidence for that hypothesis when accounting for irrigation. Furthermore, the coefficient on irrigation stays unchanged.

4.4 Culture

Our last set of control variables measure religion and cultural fractionalization. People with the same religious beliefs often share cultural values and these values could affect political institutions and development. For instance, Weber (1930) famously linked the rise of capitalism to Protestantism. More recently, Bruce (2004) describes how Protestant culture can be conducive to democracy. It has also been debated whether Islamic culture and democracy is incompatible.[44] To address these debates, we include the fraction of Muslims and Protestants in the population in the regressions in column (2) and (3) of Table 7. The signs of their respective coefficients are as expected: Muslims are associated with less democracy, and Protestants with more. Only the coefficent for Protestants is significant at the 10-percent level, however. While insignificant, including the share of Muslims in the regressions reduces the coefficient of

[43] Acemoglu *et al.* (2001, 2002). use settler mortality and not malaria ecology as a measure of the disease environment. It is admittedly a more direct measure, but only available for a small sample of colonies. Moreover, settler mortality is insignificant in a regression based on the smaller sample where data is available.

[44] See *e.g.*, Bellin (2004), Huntington (1993), Kedourie (1992).

irrigation potential somewhat. This is hardly surprising, since most Muslim countries are arid and heavily dependent on irrigation.

It should be noted that cultural values and habits in many ways reflect the economic realities societies have faced throughout history. The religious control variables may thus be endogenous, and the results should be treated with caution.

Cultural heterogeneity may also be a barrier to inclusive democracy. Alesina *et al.* (2003) construct three measures of cultural heterogeneity based on ethnic, linguistic, and religious fractionalization, and find that all three are negatively correlated with institutional quality. The effect of irrigation potential is, as shown in columns 4-6 of Table 7, robust to adding the Alesina *et al.* (2003) measures of cultural heterogeneity to the regression.[45]

In the final column we add all cultural control variables simultaneously. The coefficient for *irrigation potential* is the only significant coefficient.

Table 7. Democracy on irrigation potential controlling for cultural values and fractionalization

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Irrigation potential (%)	-5.816***	-3.720*	-5.579***	-5.767***	-5.846***	-5.795***	-3.524*
	(1.586)	(2.133)	(1.618)	(1.565)	(1.670)	(1.653)	(2.077)
Muslims (%)		-3.337					-3.287
		(2.076)					(2.294)
Protestants (%)			3.165*				2.208
			(1.701)				(1.660)
Ethnic fractionalization				-2.789			-3.853
				(1.907)			(2.549)
Linguistic fractionalization					-0.182		2.349
					(1.726)		(2.393)
Religious fractionalization						0.091	-1.707
						(1.629)	(2.076)
Observations	149	149	149	149	149	149	149
R-squared	0.517	0.534	0.523	0.526	0.517	0.517	0.549
Continent dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: OLS estimates. The dependent variable is the polity2 index which ranges from -10 (least democratic) to 10 (most democratic). Irrigation potential ranges from 0 to 1 and measures the fraction of arable land where irrigation can more than double agricultural yields compared to rainfed agriculture. Muslims is the share of Muslims in the population in year 2000. Likewise for Protestants. Ethnic fractionalization measures the probability that two randomly drawn individuals are not from the same ethnic group. Likewise for linguistic and religious fractionalization. ***, **, and * indicate significance at the 1, 5, and 10% level, respectively. All regressions include a constant. Robust standard errors in parentheses.

[45] The simple correlation between polity2 and ethnic and language fractionalization is negative and significant, while both relations turn insignificant as continent dummies are included. The relation between religious fractionalization and *polity*2 is insignificant throughout.

4.5 IV estimates

So far, our regressions have been in reduced form, where actual historical irrigation was proxied by irrigation potential. As argued earlier, accurate historical irrigation data is not available, and present-day irrigation may not capture the effect we are interested in. We therefore regard the reduced form regressions as our main empirical results. But in this section we report the results of instrumental variable regressions as a robustness check. Irrigation potential is used as an instrument for actual irrigation.

Freydank and Siebert (2008) provide estimates for the total area equipped for irrigation in years 1900-2003. We face a tradeoff between using historical, but inaccurate data and using contemporary more accurate data. As stressed in Section 4, less than 15 percent of the observations in 1900 are based on actual data, compared to 95 percent of the observations in 2000. Either measure, though, is an imprecise measure of actual historic irrigation, which is what we are interested in. We show results for 1900 and 2000 for which we have calculated area equipped for irrigation as a share of arable land.

Table 8 shows the OLS results from regressing *polity*2 on area equipped for irrigation in 1900 (panel A) and 2000 (panel B). The table uses the same basic geographical control variables as Table 3. Irrigation is negatively related to *polity*2 across all columns, although not always significantly so. As expected, the correlation is lower in year 2000.[46] This corresponds well to the fact that irrigation in year 2000 does not have the same features of a point-source resource and thus cannot be expected to be as detrimental to institutions.

[46]The difference between the 1900 and 2000 estimates is larger than what is visible from the table, as irrigation 1900 ranges from 0 to 0.58, while irrigation 2000 ranges from 0 to 1.

Table 8. OLS estimates of democracy on area equipped for irrigation 1900 and 2000

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Panel A. Irrigation measured in year 1900							
Area equipped for irrigation 1900 (%)	-18.626***	-7.354*	-8.219*	-3.884	-8.718**	-7.660*	-4.695
	(4.767)	(4.384)	(4.465)	(4.767)	(4.156)	(4.362)	(4.340)
Absolute latitude			0.031				0.093
			(0.035)				(0.064)
Precipitation				1.658**			3.079***
				(0.728)			(0.882)
Temperature					-0.120*		-0.074
					(0.065)		(0.102)
Soil constraints (%)						-3.796	-4.119
						(4.910)	(4.685)
Observations	159	159	159	159	159	159	159
R-squared	0.046	0.417	0.419	0.438	0.431	0.419	0.474
Panel B. Irrigation measured in year 2000							
Area equipped for irrigation 2000 (%)	-6.385**	-2.821	-3.104	-1.469	-3.260	-2.935	-1.612
	(2.626)	(2.154)	(2.191)	(2.063)	(2.117)	(2.141)	(1.922)
Absolute latitude			0.029				0.092
			(0.034)				(0.064)
Precipitation				1.653**			3.068***
				(0.690)			(0.861)
Temperature					-0.118*		-0.072
					(0.065)		(0.102)
Soil constraints (%)						-3.736	-4.142
						(5.030)	(4.766)
Observations	160	160	160	160	160	160	160
R-squared	0.041	0.420	0.422	0.441	0.433	0.422	0.477
Continent dummies	No	Yes	Yes	Yes	Yes	Yes	Yes

Notes: OLS estimates. The dependent variable is the polity2 index which ranges from -10 (least democratic) to 10 (most democratic). The irrigation measure in panel A is area equipped for irrigation as a share of arable land in year 1900, while the corresponding irrigation variable in panel B is measured in year 2000. All geographical variables are computed by averaging over the modern-day borders of the country. Temperature is average daily temperature over the period 1961-1990 in degrees Celsius. Precipitation is the average daily precipitation over the period 1961-1990 in meters. Soil constraints is the fraction of land with more than few soil and terrain constraints to crop growth. ***, **, and * indicate significance at the 1, 5, and 10% level, respectively. All regressions include a constant. Robust standard errors in parentheses.

The relation between actual irrigation and *polity*2 is potentially biased by endogeneity. For instance, richer countries have better means to undertake irrigation projects and may, according to the modernization hypothesis, also be more democratic. This would create a spurious positive relation between irrigation and democracy. Indeed, once we instrument actual irrigation with our irrigation potential measure in Table 9, the estimate on irrigation increases in absolute terms. As expected, irrigation potential is a weak instrument in most specifications (the Kleibergen-Paap F-statistic is below 10).[47] Estimated area equipped for irrigation is a

[47]The instrument would have been judged stronger had we instead used the Cragg-Donald F-statistic, which

noisy measure of historical irrigation, which by construction generates a weak relation with irrigation potential. The instrument is somewhat stronger when year 2000 is used, which corresponds well to the fact that more actual data is used to calculate this year. In all columns, the Anderson Rubin p-value shows that the estimate on irrigation is significantly different from zero.

Again, irrigation exerts a smaller impact on *polity*2 in year 2000 than in year 1900.

Table 9. IV estimates of democracy on area equipped for irrigation 1900 and 2000

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Panel A. Irrigation measured in year 1900							
Area equipped for irrigation 1900 (%)	-107.933**	-79.487*	-100.302	-109.622	-76.805*	-83.499	-70.420
	(43.853)	(47.208)	(64.179)	(101.900)	(43.751)	(51.099)	(55.649)
Absolute latitude			0.141*				0.087
			(0.076)				(0.089)
Precipitation				-1.554			1.181
				(2.417)			(1.674)
Temperature					-0.215*		-0.114
					(0.120)		(0.168)
Soil constraints (%)						-8.503	-5.072
						(6.594)	(5.077)
Observations	159	159	159	159	159	159	159
Kleibergen Paap F-statistic	6.404	3.224	2.576	1.172	3.363	2.944	1.697
Anderson Rubin p-value	0.000	0.000	0.000	0.003	0.000	0.000	0.033
Panel B. Irrigation measured in year 2000							
Area equipped for irrigation 2000 (%)	-38.508***	-30.846**	-37.856**	-40.792	-29.896**	-32.352**	-27.589
	(11.921)	(14.458)	(18.832)	(29.584)	(13.302)	(15.265)	(18.461)
Absolute latitude			0.122*				0.074
			(0.069)				(0.087)
Precipitation				-1.320			1.049
				(2.350)			(1.871)
Temperature					-0.196*		-0.111
					(0.113)		(0.161)
Soil constraints (%)						-8.210	-5.107
						(6.167)	(5.136)
Observations	160	160	160	160	160	160	160
Kleibergen Paap F-statistic	11.95	6.114	4.647	2.080	6.493	5.558	3.003
Anderson Rubin p-value	0.000	0.000	0.000	0.003	0.000	0.000	0.031
Continent dummies	No	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Second stage IV estimates. The dependent variable is the polity2 index which ranges from -10 (least democratic) to 10 (most democratic). The irrigation measure in panel A is area equipped for irrigation as a share of arable land in year 1900, while the corresponding irrigation variable in panel B is measured in year 2000. Both are instrumented with irrigation potential. All geographical variables are computed by averaging over the modern-day borders of the country. Temperature is average daily temperature over the period 1961-1990 in degrees Celsius. Precipitation is the average daily precipitation over the period 1961-1990 in meters. Soil constraints is the fraction of land with more than few soil and terrain constraints to crop growth. ***, **, and * indicate significance at the 1, 5, and 10% level, respectively. All regressions include a constant. Robust standard errors in parentheses.

is, however, not robust to heteroskedasticity.

5 Subnational evidence

We now turn to subnational evidence on the link between irrigation and autocracy. The main challenge is to find suitable outcome variables, as many democratic institutions are established at the national level. However, it is possible to obtain subnational data on individuals' attitudes towards democracy and we use this as our first outcome variable. Our second outcome variable is a historical indicator of whether a society was governed by an elite who obtained its power from natural resources. We get this measure from a data set of ethnographic societies surveyed before contact with Europeans.

5.1 Attitudes towards democracy

The World Values Survey and the European Values Study provide information on individuals' views on a broad range of issues, including democracy. We cannot say whether more favorable views of democracy is a cause of local democracy, or whether the causality goes in the other direction. But in both cases attitudes towards democracy should be linked to the actual quality of local institutions.

The surveys divide countries into multiple subnational regions, and we match the survey results in each region with irrigation potential in that region.[48] This enables us to estimate regressions of the form:

$$democracy_{idct} = \alpha_0 + \alpha_1 irrigation_{dc} + a_c + \lambda_t + X'_{idct}\beta + W'_{dct}\delta + u_{idct} \tag{3}$$

for individual i interviewed in subnational district d in country c at time t. *democracy* measures individuals' expressed values for democracy, *irrigation* measures either irrigation potential or irrigation in year 2000 measured at the subnational district level.[49] a_c is country-fixed effects, λ_t is time fixed-effects. X_{idct} is a vector of individual controls, and W_{dct} a vector of geographical controls at the district level. As the dependent variable varies at the individual level and the independent variable varies only at the district level, we cluster the standard errors at the district level. One concern is that individuals' values for democracy are influenced by country-wide institutions. We therefore always include country fixed effects, a_c.

[48] The methodology of matching the individuals to the geographic shapefiles is described in more detail in Bentzen (2013) in a different context.

[49] Unfortunately, area equipped for irrigation in year 1900 is not available at the grid level, so we cannot calculate district-level averages for this measure.

We pool all currently available waves (1981-2009) of the World Values Survey and European Values Study.[50] We use two measures of democracy in our analysis. The first is based on respondents' expressed opinion (on a scale from 1 to 4) about whether a democratic political system is very good (4), fairly good (3), fairly bad (2) or very bad (1).[51] This variable enters in columns (1)-(2) in Table 10 and is labelled *demo_good*. The second measure is based on a question that asked whether respondents agreed with the following statement: "Democracy may have problems but it is better than any other form of government". Respondents answered strongly disagree (1), disagree (2), agree (3), and strongly agree (4).[52] This variable enters in columns (3)-(4) in Table 10 and is labelled *demo_better*.

Panel A of Table 10 shows the impact of irrigation potential on *demo_good* and *demo_better*. All columns control for country and time fixed effects, age, age squared, gender, marital status, agricultural occupation, and income- and educational attainment fixed effects. Columns (2) and (4) add the basic geographical controls at the subnational district level: absolute latitude, precipitation, temperature, and soil constraints.

The results in all columns of Table 10 show that individuals value democracy less when residing in subnational districts with higher irrigation potential.

[50] The individual years in which an interview took place are 1981, 1984, 1990, 1991, 1995, 1996, 1997, 1998, 1999, 2000, 2001, 2001, 2003, 2004, 2005, 2006, 2007, 2008, and 2009.

[51] This is variable e117 from the pooled WVS / EVS.

[52] This is variable e123 from the pooled WVS / EVS.

Table 10. OLS and IV estimates of democratic values on area equipped for irrigation 2000

	(1)	(2)	(3)	(4)
Dependent variable	demo_good	demo_good	demo_better	demo_better
Panel A. Reduced form OLS estimates				
Irrigation potential (%)	-0.069**	-0.056*	-0.054*	-0.060*
	(0.030)	(0.032)	(0.031)	(0.031)
R-squared	0.108	0.110	0.099	0.101
Panel B. Second stage IV estimates				
Area equipped for irrigation 2000, % of arable land	-0.179**	-0.280*	-0.132*	-0.279**
	(0.084)	(0.152)	(0.072)	(0.132)
Kleibergen-Paap F-statistic	32.19	12.80	29.83	9.383
Anderson Rubin p-value	0.0213	0.0226	0.0780	0.0267
Observations	95,956	95,031	62,245	61,578
Baseline controls	Y	Y	Y	Y
Geo controls	N	Y	N	Y
Countries	70	70	52	52
Regions	747	740	485	481

Notes. The unit of analysis is individuals. The dependent variable is answers to whether the respondent thinks that a democratic system is very bad (scores 1), fairly bad (2), fairly good (3), or very good (4) in col (1)-(2) and whether the respondent disagrees strongly (scores 1), disagrees (2), agrees (3), or strongly agrees (4) with the claim that democracy may have problems, but is the best political system in col (3)-(4). Irrigation potential ranges from 0 to 1 and measures the fraction of arable land where agricultural yields can be at least doubled by engaging in irrigation compared to rainfed agriculture. Panel A shows reduced form OLS estimates of democratic values on irrigation potential, while panel B shows IV estimates of democratic values on area equipped for irrigation instrumented with irrigation potential. All regressions include country and year of interview fixed effects, age, age squared, a male dummy, a married dummy, a dummy for agriculture worker, and 10 income and 8 education fixed effects (Baseline controls). Geo controls refers to whether district level controls for absolute latitude, precipitation, temperature, and soil constraints are included. Standard errors, clustered at the subnational district level, are reported in parentheses. Asterisks ***, **, and * indicate significance at the 1, 5, and 10% level.

The panel A results can be regarded as reduced form results corresponding to the cross-country results in Section 4. Panel B of Table 10 shows the corresponding second stage IV results, where irrigation in equation 3 is instead measured by actual area equipped for irrigation in year 2000, instrumented with irrigation potential. The Kleibergen-Paap F-statistic indicates that irrigation potential is a strong instrument across all columns. Again, the IV estimates are larger in absolute value than the OLS estimates, most likely because the IV strategy removes the spurious positive relation between irrigation and democracy caused by omitting development levels.

The IV-estimates confirm the link between irrigation and negative views of democracy. The subnational evidence thus confirms the finding that areas that have engaged more in irrigation have been more likely to develop values that oppose democracy. The relation is not caused by country-level variation in institutions or geography or any other variation at the country level. Whether this local effect stems from the historical distribution of power cannot be judged from this exercise. This question motivates the analysis in the next section.

5.2 The Ethnographic Atlas

We now move back in history using data from the Ethnographic Atlas to measure democratic institutions at the indigenous societal level (Murdock (1967)). The Atlas is based on ethnographic evidence from traditional societies scattered around the globe, mostly from the 19th and early 20th century. The data set includes latitude and longitude for each society centre, and it is therefore possible to calculate our geographical variables at the local level.

There is no direct measure of autocracy or democracy in the Ethnographic Atlas.[53] Instead we use social stratification as an indicator of the distribution of power in the society. The ethnographic societies are classified into five different groups based on the social stratification prevalent: complex stratification, hereditary aristocracy, elite stratification, wealth distinctions, and no stratification.[54] A society with elite stratification is, according to the definition given in the Ethnographic Atlas, a society "...in which an elite class derives its superior status from, and perpetuates it through, control over scarce resources, particularly land, and is thereby differentiated from a propertyless proletariat or serf class."[55] We use elite stratification as our dependent variable as it directly captures the sort of power distribution we are interested in.[56]

We construct a variable called *elite*, which equals 1 if the society has elite stratification and 0 if it is placed in one of the other categories.[57] With this definition, 45 societies out

[53] There are some democracy indicators in the related Standard Cross-Cultural Sample (SCCS). Unfortunately, there are too few observations for our purpose, and mostly from societies of hunters and gatherers where irrigation is not relevant to the distribution of power.

[54] These are variables V66 (Class stratification) and V67 (Class stratification, secondary features) in the Ethnographic Atlas.

[55] Another variable from the Ethnographic Atlas that could potentially be used to grasp the degree of local democracy is based on the classification of election rules involved with the succession of the local headman. However, this is not as direct a measure of what we are after and, in fact, in line with the reasoning by Wittfogel (1957), we find no impact of irrigation potential on this variable. A strong landed elite can exist side by side with an elected local headman.

[56] Admittedly, power may be centralized in societies with hereditary aristocracy. Yet, without control of resources, an aristocracy is likely to have faced more constraints on their execution of power than a resource controlling elite.

[57] In some cases there are two classification systems prevailing at the same time. Here, we set elite equal to

of a total of 826 societies where data is available are coded as $elite = 1$.[58] Before running regressions at the disaggregated level, we check whether the *elite* variable is indeed a good indicator of subsequent autocratic institutions. To this end, we average our elite variable across ethnographic societies within each country and compare the results to the present-day *polity*2 index. The correlation, depicted in Table is -0.23 and significant, indicating that areas with elite stratification historically are more likely to have turned into autocratic states today.[59] We also check that *elite* is a better measure than the other stratification categories. Table shows the simple correlation between the *polity*2 index and the 5 stratification categories. Elite stratification has the numerically highest correlation coefficient with the *polity*2 index among all 5 categories. The only other significant coefficient is the one for complex stratification. This coefficient has the opposite sign; societies with a complex stratification are more likely to end up with democratic institutions today. Since complex stratification is vaguely defined, no clear conclusions can be drawn from this correlation. We thus proceed to use elite stratification as measure of historical local institutions that lead to autocracy.

Table 11. Simple correlations between polity2 and stratification

	*polity*2
Stratification based on:	
- Absence among free men	0.08
- Wealth distinctions	-0.13
- Elite control of resources	-0.23**
- Dual (hereditary aristocracy)	-0.11
- Complex (social classes)	0.19**
Observations	115

Notes: Simple correlations between the polity2 index and the five stratification groups across 115 countries. The stratification measures are aggregated up to the country level using present-day borders. ***, **, and * indicate significance at the 1%, 5%, and 10% level, respectively.

We run regressions of the form:

$$elite_{sl} = \alpha_0 + \alpha_1 irrigation\ potential_s + a_l + X_s' \beta + u_{sl} \tag{4}$$

where $s = 1, ..., 770$ indexes ethnographic societies.[60] We expect that $\alpha_1 > 0$, meaning that irrigation increased elite stratification. *irrigation potential* and all the geographical control

one if one of the systems are elite stratification.

[58] We restrict the sample to include only societies using agriculture since irrigation does not matter for stratification in a society without it. Moreover, there are no non-agricultural societies with elite stratification.

[59] There are in total 115 present day countries with one or more observations of ethnographic societies that we can match with the *polity*2 measure. 27 of the countries have elite based societies.

[60] Of the 826 societies with data on agriculture and elite stratification, 770 also have data on irrigation potential. The societies lacking irrigation potential data are primarily located at sea.

variables are calculated within a 200 km radius of the society centre. In addition to continent fixed effects, we include 55 language group fixed effects, a_l, since a shared language likely indicates a shared cultural and historical background. We thereby remove variation in the elite variable caused by a shared culture and history.

The simple regression coefficient between *irrigation potential* and *elite* is shown in Table 12, column (1). It is 0.168 and highly significant. When language - and continent fixed effects are introduced in column (2), the estimated coefficient doubles. The effect of irrigation on elite stratification therefore seems to have happened within cultural groups rather than between them.[61]

Table 12. Elite stratification on irrigation potential controlling for geographical factors

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Estimation method	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	probit
Irrigation potential (%)	0.168***	0.325***	0.328***	0.319***	0.322***	0.316***	0.327***	0.297***	1.250***
	(0.041)	(0.104)	(0.108)	(0.103)	(0.105)	(0.101)	(0.105)	(0.096)	(0.192)
Year			0.000					0.000	0.000
			(0.000)					(0.000)	(0.000)
Absolute latitude				0.079				0.252*	1.564
				(0.077)				(0.138)	(1.411)
Precipitation					-0.000			0.000	-0.003
					(0.000)			(0.000)	(0.002)
Temperature						0.004		0.006	0.052
						(0.002)		(0.004)	(0.036)
Soil constraints (%)							0.050	0.016	-1.050
							(0.112)	(0.086)	(0.796)
Observations	770	770	770	770	770	770	770	770	770
R-squared	0.057	0.221	0.222	0.221	0.221	0.224	0.221	0.228	.
Continent and 55 language dummies	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Estimates of elite on irrigation potential across ethnographic societies. OLS estimation is used in columns (1)-(8) and probit estimation is used in column (9). The dependent variable, elite, is a dummy variable equal to one if the society is socially stratified and ruled by an elite which bases its power on control of a natural resource, and zero otherwise. All geographical variables are computed using the grid cells within 200 km of the society centre. Irrigation potential ranges from 0 to 1 and measures the fraction of arable land where irrigation can more than double agricultural yields compared to rainfed agriculture. Year is the year of observation of the ethnographic society. Precipitation is the average daily precipitation in meters. Temperature is average daily temperature in degrees Celsius. Soil constraints is the fraction of land with more than few soil and terrain constraints to crop growth. ***, **, and * indicate significance at the 1, 5, and 10% level, respectively. All regressions include a constant. Robust standard errors clustered at the language-group level in parentheses.

[61] Both the introduction of continent - and language group fixed effects increases the estimate on irrigation potential. However, the latter is responsible for the largest part of the increase.

Column (3) of Table 12 includes the year a given society was observed with no consequence for the results. Columns (4)-(8) show that absolute latitude is the only geographical control that obtains significance, but only when all geographical variables are included jointly. Column (9) reports the results from a probit estimation. The estimate of irrigation potential remains positive and significant at the 1% level.

It could be that elite stratification requires a certain level of economic development absent in primitive societies. If that is the case, the estimated effect of irrigation potential could run through development, and not through the channels outlined in this paper. We control for settlement complexity and agricultural intensity in Table 13, but none of these variable exert a significant effect on *polity*2.

Table 13. Elite stratification on irrigation potential controlling for development factors

	(1)	(2)	(3)	(4)	(5)
Estimation method	OLS	OLS	OLS	OLS	probit
Irrigation potential (%)	0.328***	0.328***	0.317***	0.316***	1.665***
	(0.108)	(0.109)	(0.083)	(0.083)	(0.234)
Agricultural intensity		0.000		0.002	0.019
		(0.009)		(0.010)	0.090)
Settlement complexity			-0.006	-0.006	-0.034
			(0.015)	(0.015)	(0.101)
Observations	770	770	770	770	770
R-squared	0.222	0.222	0.223	0.223	.
Continent and 55 language dummies	Yes	Yes	Yes	Yes	Yes

Notes: Estimates of elite on irrigation potential for ethnographic societies, columns (1)-(4) estimated with OLS, column (5) estimated with probit. The dependent variable, elite, is a dummy variable equal to one if the society is socially stratified and ruled by an elite which bases its power on control of a natural resource, and zero otherwise. All geographical variables are computed using the grid cells within 200 km of the society centre. Irrigation potential ranges from 0 to 1 and measures the fraction of arable land where irrigation can more than double agricultural yields compared to rainfed agriculture. Settlement complexity measures, on a scale from 1 to 8, the permanency and density of settlements. Agricultural intensity runs from 1 to 4, where 1 is casual agriculture and 4 is intensive agriculture. ***, **, and * indicate significance at the 1%, 5%, and 10% level, respectively. All regressions include a constant and a control for the year of observation. Robust standard errors clustered at the language-group level in parentheses.

The evidence across ethnographic societies therefore supports the theory. The coefficient on irrigation potential is positive and highly significant throughout all specifications. Ethnographic societies in areas where irrigation was worthwhile are more likely to have been dominated by a resource controlling elite that, in turn, might have inhibited democratization later on.

For the ethnographic societies, a variable exists that measures whether or not the society relied on irrigation at the time of observation. Unlike the historical data across countries, this is not based on estimates. From the variable measuring the intensity of agriculture we construct an irrigation dummy variable which is equal to 1 if intensive agriculture is based on irrigation, and 0 if intensive agriculture is not based on irrigation. The variable is missing for lower degrees of agriculture. Table 14 shows the IV results from instrumenting the irrigation dummy with irrigation potential including the basic geographical controls. The instrument is strong throughout (the Kleibergen-Paap F-statistic is larger than 10), and the estimate on irrigation is significant at the 1% level, though only at the 10% level when probit estimation is used in column (9).

Table 14. IV of elite stratification on irrigation potential controlling for development factors

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Estimation method	IV	IV	IV	IV	IV	IV	IV	IV	IVprobit
Irrigation dummy	0.475***	0.686***	0.694***	0.731***	0.648***	0.632***	0.695***	0.495***	1.487*
	(0.170)	(0.217)	(0.182)	(0.198)	(0.217)	(0.167)	(0.181)	(0.185)	(0.871)
Absolute latitude				-0.272				-0.026	-0.134
				(0.314)				(0.321)	(2.356)
Precipitation					-0.000			-0.001	-0.011
					(0.001)			(0.001)	(0.008)
Temperature						0.010**		0.010**	0.082**
						(0.005)		(0.005)	(0.040)
Soil constraints (%)							0.235	0.069	-1.057
							(0.222)	(0.197)	(1.349)
Observations	280	280	280	280	280	280	280	280	280
Continent dummies	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Language dummies	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Kleibergen Paap F	27.86	19.56	30.76	24.81	17.78	33.63	30.18	21.57	.

Notes: IV estimates of elite on actual historical irrigation, where actual irrigation is instrumented with irrigation potential. The dependent variable, elite, is a dummy variable equal to one if the society is socially stratified and ruled by an elite which bases its power on control of a natural resource, and zero otherwise. Irrigation equals one if the society engages in intensive irrigated agriculture and zero if the society engages in intensive agriculture without irrigation. All geographical variables are computed using the grid cells within 200 km of the society centre. Irrigation potential ranges from 0 to 1 and measures the fraction of arable land where irrigation can more than double agricultural yields compared to rainfed agriculture. Year is the year of observation of the ethnographic society. Precipitation is the average daily precipitation in meters. Temperature is average daily temperature in degrees Celsius. Soil constraints is the fraction of land where there are few or little soil constraints which inhibit crop growth. Arable land is the fraction of land where the climate, soil quality, and water sources permit crop growth. ***, **, and * indicate significance at the 1, 5, and 10% level, respectively. All regressions include a constant and a control for the year of observation. Robust standard errors clustered at the language-group level in parentheses.

Note that of all the three IV exercises done throughout (in the cross-country sample, the

WVS, and the ethnographic sample), irrigation potential is the strongest instrument for irrigation in the sample of ethnographic societies. This corresponds well with the fact that historical irrigation is measured with highest precision in the ethnographic sample.

6 Conclusion

We have tested the theory that societies with a history of irrigation-based agriculture have developed more autocratic institutions compared to societies with a history of rain-fed agriculture. Such a link has been hypothesized by many prominent scholars throughout history, including Marx (1853) and Wittfogel (1957), but it can best be understood through the lens of more recent resource curse theories. Dams and canals that provide water for irrigation are easy to control, scarcity in arid areas makes it valuable. Ease of control and high value classify irrigated agriculture as a point-source resource, a class of natural resources shown to inhibit democratization if found in abundance. On the other hand, rainfed agriculture resembles more a diffuse resource, which is not expected to deter democracy.

Since adoption of irrigation may be influenced by existing institutions and the degree of economic development, we use an exogenous measure of irrigation potential to estimate a causal effect of historical irrigation on autocracy. The measure is correlated with actual use of irrigation, both today and historically.

We find that countries in areas with a high potential for irrigation are more autocratic today as measured by the *polity*2 index from the Polity IV database. Our results are robust to a wide range of geographical, climatic, cultural, and historical control variables. According to our estimates, the difference between a country with no irrigation potential and a country with full irrigation potential is about six points on the 21 point *polity*2 scale. By implication, the difference in irrigation potential can account for the gap in institutional quality between Turkey and Algeria. At a more disaggregated level, we document that individuals in regions with a high irrigation potential have less favorable views on democracy. Moreover, premodern societies were more likely to be ruled by a natural resource-controlling elite if their agriculture was based on irrigation.

As the example with Turkey and Algeria shows, the magnitudes involved are quite large. Contemporary effects of irrigation on institutions are unlikely to generate such differences, and they should be seen as the outcome of a long historical process. Irrigation fostered a concentration of power and wealth in the hands of a small elite. The elite entrenched itself through non-democratic institutions, and both the elite and the institutions were consequently able to survive even when the economic importance of agriculture declined.

The results of this paper contribute to the literature on the origins of institutions. Much attention has been paid to economic development and to historical contingencies related to, for example, colonization. However important these determinants might be, a significant fraction of global variation in institutional quality can still be traced to deeply rooted geographical factors. The supply of water is one, as we show in this paper.

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A Appendix

Table A1. Democracy on irrigation potential controlling for geography

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Irrigation potential (%)	-5.79***	-5.75***	-5.78***	-5.99***	-5.72***	-7.38***	-5.90***	-5.17***	-8.16***	-8.32***
	(1.54)	(1.51)	(1.56)	(1.69)	(1.52)	(1.96)	(1.53)	(1.94)	(1.92)	(2.66)
Terrain ruggedness, 100 m.		0.03								-0.48
		(0.34)								(0.44)
Landlocked			-0.79							-0.28
			(0.99)							(1.22)
Malaria ecology index				-0.04						0.03
				(0.08)						(0.07)
Land within 100km of coast/river (%)					0.53					0.84
					(1.29)					(1.70)
Land within tropics (%)						-0.02*				-0.03*
						(0.01)				(0.02)
Total area							0.00*			0.00
							(0.00)			(0.00)
Std.dev yearly precipitation 1961-1990								0.00		0.01*
								(0.01)		(0.01)
Arable land (%)									-3.20**	-3.51
									(1.45)	(2.21)
Observations	158	158	158	158	158	158	158	158	158	158
R-squared	0.47	0.47	0.48	0.48	0.48	0.49	0.48	0.48	0.49	0.52
Continent dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: OLS estimates. The dependent variable is the polity2 index which ranges from -10 (least democratic) to 10 (most democratic). Irrigation potential ranges from 0 to 1 and measures the fraction of arable land where irrigation can more than double agricultural yields compared to rainfed agriculture. All geographical variables are computed by averaging over the modern-day borders of the country. Ruggedness measures the variability of altitude. Landlocked is a dummy equal to one if the country is landlocked and zero otherwise. The malaria ecology index measures the contribution of vectors to the force of malaria transmission. Arable land is the fraction of land where the climate, soil quality, and water sources permit crop growth, calculated by adding across impact classes 1-5. ***, **, and * indicate significance at the 1, 5, and 10% level, respectively. All regressions include a constant. Robust standard errors in parentheses.

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Structural transformation in the 20th century: Additional data documentation

Asger Moll Wingender

1 Introduction

This document provides further details on the sources and methodology used to compile the agricultural employment database presented in my paper *Structural transformation in the 20th century: A new database on agricultural employment around the world*.[1] Users of the database are advised to read that paper before reading this document.

The database contains the following variables:

- *country*
- *iso* (three-letter country code)
- *year*
- *aes* (the agricultural employment share)
- *aes_source* (the data source for aes)
- *pop* (the population of the country)

The population data are included to make it possible to calculate population weighted regional aggregates of the agricultural employment shares.

[1] Wingender (2014).

2 Data sources: Employment

The variable *aes_source* contains the data source for agricultural employment shares in a given country in a given year. The main data sources are listed below, with the name in *aes_source* in bold:

- **Deldycke et al.** Data set compiled by Deldycke *et al.* (1968).
- **Easterly and Fischer.** Data from Easterly and Fischer (1995).
- **GGDC.** Data from the Groningen Growth and Development Centre, *i.e.*, from EU-KLEMS, the Africa Sector Database [Vries *et al.* (2013)] and the 10-Sector Database [Timmer and de Vries (2009)].
- **Good.** Census data from the Habsburg empire kindly provided by David Good. The data are used in Good (1994) and Good and Ma (1998).
- **IHS**. International Historical Statistics from Mitchell (1993, 1998a,b))
- **ILO.** Data from the KLIM database (from 1980 and onwards) and the LABORSTAT database (before 1980). Both databases are maintained by The International Labor Organization
- **IPUMS.** Integrated public use micro data from national censuses made available online by Sobek *et al.* (2013).
- **League of Nations.** Various issues of the Yearbook of the League of Nations.
- **Myers and Campbell.** Historical data for the seven ex-Yugoslavian republics from Myers and Campbell (1954).
- **NAPP.** Micro level census data from the North Atlantic Population Project made available online by the Minnesota Population Center (2008).
- **OECD.** Data downloaded from http://stats.oecd.org/.
- **OLA.** Oxford Latin America Economic History Database.

A number of additional data sources, often specific to a single observation, are used and listed in Table 1.

The variable *aes_source* also states if an observation in the database is based on interpolation, or estimated from urbanization data. Some countries have interpolated agricultural employment shares in the year 1900. In these cases, the data source prior to the year 1900 used in the interpolation is stated in parenthesis. Countries with interpolated observations in 2010 are handled in the same way. There are eight countries where the earliest observation of *aes* (actual or estimated) is above 0.95. It is assumed that these countries were not more developed in earlier periods, and *aes* is consequently set to 0.95 in all prior years. These cases are denoted *Pre-development* in *aes_source*.

3 Data sources: Urban and total populations

Urbanization rates and total population data for all countries 1950-2010 are from United Nations (2012). Urban population data prior to 1950 are from Lewis *et al.* (1976) for USSR, and from Eggimann (1999) for Africa, Asia and Latin America. Data for Bulgaria are from Lampe (1975).

Total population data prior to 1950 are mostly from International Historical Statistics. Major exceptions are the USSR, where data are from Lewis *et al.* (1976), and Africa, where I rely on Manning (2010).

In a few cases, where the whole period 1900-2010 is not coverd by the International Historical Statistics, I supplement the population data with the following sources:

- McGee (1964):Malaysia.
- Karpat (1985): Turkey, Syria and Lebanon.
- McEvedy *et al.* (1978): Indonesia and the countries on the Indian subcontinent.

4 General notes on methodology

The most important aspects of the methodology I use to merge the data sets, and to estimate agricultural employment shares are described in Wingender (2014). A few methodological details not covered by the paper are discussed in this section.

Table 1: Additional sources of employment data

Country	**Year(s)**	**Type**	**Published by**
Albania	2002	Living standards survey	Institute of Statistics (INSTAT) (2002)
Angola	2002-2010	National accounts	Instituto Nacional de Estatistica (2013)
Bosnia and Herzegovina	1895	Official estimate	Almanach de Gotha (1910)
Brunei Darussalam	2006-2009	Census on employers	Prime Minister's Office et al (2010)
Cabo Verde	2000	Population census	Instituto Nacional de Estatistica Cabo Verde (2001)
Chad	2003	Employment survey	INSEED (2006)
Chad	2011	Employment survey	INSEED (2013)
Côte d'Ivoire	1985	Household survey	Direction de la Statistique, Côte d'Ivoire (1985)
Lao People's Dem. Rep.	1995	Population census	Lao Statistics Buereau (1995)
Lao People's Dem. Rep	2005	Population census	Lao Statistics Buereau (2005)
Lebanon	2009	Household survey	Central Administration of Statristics (2009)
Lesotho	2008	Labor force survey	Bureau of Statistics, Lesotho (2009)
Korea, Rep. of	1905, 1945	Colonial Statistics	Chung (2006)
Kosovo	2005	Agricultural household survey	Statistical Office of Kosovo (2006)
Kosovo	2008	Agricultural household survey	Statistical Office of Kosovo (2009)
Madagascar	1993	Population census	Institut National de la Statistique (1997)
Madagascar	2003	Population census	Institut National de la Statistique (2005)
Maldives	2007	Establishment survey	Department of National Planning (2007)
Nepal	1995, 2003, 2010	Living standard survey	Central Bureau of Statistics (2011)
Nigeria	1996, 1999, 2005, 2009	Household surveys	Adeyinka *et al.* (2013)
Netherlands	1899,1909	Population censuses	Smits *et al.* (1999)
Solomon Islands	2009	Population census	Solomon Islands National Statistical Office (2010)
Sweden	1900-2010	Various	Schön and Krantz (2012)
Timor-Leste	2001	Living standards survey	Timor Leste National Statistics Directorate (2008)
Viet Nam	1992	Living standards survey	General Statistics Office of Vietnam (1994)
Zimbabwe	2004	Labor force survey	Central Statistics Office (2006)
Zimbabwe	2012	Population census	Zimbabwe National Statistics Agency (2013)

4.1 Classifying agricultural employment in micro data

I use micro level census data from two sources. Census data from the past decades for a number of countries can be found in Sobek *et al.* (2013). Minnesota Population Center (2008) contains census data from the 19th and early 20th century for a small number of countries in the North Atlantic regions. In both data sets, the International Standard Classification of Occupations (ISCO) is used. I remove all individuals from the sample whith no occupation, or where occupation is listed as unknown/missing. The remaining observations constitute the employed labor force.

In the Sobek *et al.* (2013) data set, only the major ISCO group is reported for each individual, but agricultural workers can in principle fall in both the "skilled agricultural and fishery workers" group and the "elementary occupations" group. Fortunately, most countries seems to classify agricultural workers in the former category no matter their skill levels There are exceptions, such as Sierra Leone, where a large portion of agricultural workers are classified as being employed in elementary occupations together with persons working as, *e.g.*, street vendors, cleaners, and unskilled factory workers. I remove such countries from the sample.

Occupations in the historical census data from Minnesota Population Center (2008) are reported at a more disaggregated level. But many of the groups in the data are servants, maids, relatives helping at home, and similar sounding occupations that are likely to have a substantial agricultural component. Fortunately, in the case of Sweden, most individuals have their occupations transcribed directly from the original census records, and these give an indication of whether an ISCO-group is primarily engaged in agriculture. I assume that Swedish pattern applies to the other countries. The resulting agricultural employment shares are similar to the ones obtained from other sources in years where other sources are available. For example, Canada had 42.6 percent of its labor force employed in agriculture in 1901 according to International Historical Statistics, compared to 41.9 percent in my calculations.

4.2 Level adjustments

Population data from two sources do not always agree in years where they overlap. For instance, I use population data from United Nations (2012) from 1950-2010, and other data in earlier periods. The other data sources sometimes report a slightly different number of inhabitants in a given country in 1950 than the United Nations does. To merge the data series, I rescale the non-UN data to be consistent with the level of the United Nations (2012) data in 1950 (or equivalently, I use the growth rates from the other series to extend the UN data back in time). The same strategy is used in a few cases where agricultural employment shares from two data sources do not match completely, but only for countries where the difference is neglegible. These observations, all of them from ILO, are listed as *ILO, adjusted* in *aes_source*.

4.3 Interpolation prior to 1950

The urban populations in Eggimann (1999) are only reported in years divisible by 10, and I have for that reason only collected population data for those years. Both series are interpolated in the remaining years based on the average annual growth rate between observations.

4.4 Yugoslavia and Czechoslovakia

Employment data for the seven ex-yugoslavian republics are available from various sources in the past decade, from Myers and Campbell (1954) in 1948. Additional data are available for the parts of Yugoslavia that was a part of the Habsburg Empire prior to World War I. In the intermediate years, I use the aggregate data for Yugoslavia to derive the growth path of agricultural employment in the republics between the actual data points. A similar strategy is followed in the two Czechoslovak Republics.

5 Country notes

Albania: Urbanization data prior to 1950 are from United Nations (1969).
Austria: IHS data are adjusted in 1920 and 1934 to take undercounting of females in agriculture into account. The missing women are in the 1920 census counted as employed, but without a specific occupation. They are not enumerated in the 1934 census. To adjust the numbers, it is assumed that the ratio of women–to men in agriculture is the same as in the 1939 census.

Brunei Darussalam: The Statistical Yearbook do not report occupations for self-employed. I assume that they are evenly distributed across all sectors, except for the government sector.
Czech Republic: Employment growth from Czechoslovakia is used to calculate agricultural employment shares in the period 1921-1991 using the same approach as for the Yugoslavian republics (see Section 4.4). Women in agriculture are in the Czechoslovak employment data from 1921 undercounted. The data are adjusted by assuming that the ratio of males-to-females in agriculture is the same as in 1930.
Germany: Population weighted average of East Germany and West Germany during the partition.
Hungary: Employment data from 1900 and 1910 are corrected for undercounted women in agriculture using the method suggested by Schulze (2007).
Ireland: Present day borders prior to 1920. Population growth is assumed to be identical in the Republic of Ireland and in Northern Ireland before 1920.
Korea, Rep. of: The agricultural employment share within the borders of present day South Korea is in the colonial era assumed to be the same as on the entire Korean Peninsula.
Kosovo: Employment rates of 50 percent are assumed when agricultural employment shares are derived from Statistical Office of Kosovo (2006, 2009). Population data are from the website of the Statistical Office of Kosovo.
Lebanon: Population data for 1914 are obtained from Karpat (1985) by adding the innhabitants from the Tripoli and Beirut census areas.
Malaysia: Population growth in Sarawak is assumed to be equal that of Sabah before 1940
Philippines: The population in 1900 is extrapolated from 1903 using average population growth 1903-1910.
Poland: Agricultural employment is adjusted for family workers in 1897. The number of family workers in agriculture is reported in a footnote to the employment table in Deldycke *et al.* (1968).
Romania: Population data are adjusted for boundary changes by the author prior to 1920. Data from 1910 and 1900 cover only the regions part of the Hungarian Kingdom. Employment data from 1900 and 1910 are corrected for undercounted women in agriculture using the method

suggested by Schulze (2007)

Serbia: Data for 1900 and 1910 are only available for Voivodina (roughly one third of Serbia in terms of population). I calculate agricultural employment shares in Serbia as a whole by assuming that the ratio of agricultural employment in Voivodina to agricultural employment Serbia Proper was the same in 1900 and 1910 as it was in 1948, where data are available in Myers and Campbell (1954).

Slovakia: Employment growth from Czechoslovakia is used to calculate agricultural employment shares 1921-1991 (see Section 4.4). Women in agriculture are in the Czechoslovak employment data from 1921 undercounted. The data are adjusted by assuming that the ratio of males-to-females in agriculture is the same as in 1930. Employment data from 1900 and 1910 are corrected for undercounted women in agriculture using the method suggested by Schulze (2007).

Syrian Arab Republic: The population before World War I is calculated from census data reported by Karpat (1985). The census regions Hama, Halep, Lazkiye and Damaskus approximate present day Syria.

Turkey: he population before World War I is calculated from census data reported by Karpat (1985). The census regions Aydin, Erzurum, Adana, Ankara, İzmit, Bitlis, Biga, Çatalca, Hüdavendigar, Diyarbekir, Zor, Sivas, Şehremaneti, Mülhakati,Trabzon, Kastamonu, Konya, Kudüs, Elaziz, Van, and Dersaadet ve Bilad-i Selase approximate present day Turkey.

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